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Monterey, California



THESIS

THERMAL ANALYSIS AND DESIGN OF AIR COOLED
ELECTRONIC CIRCUIT BOARDS USING
A DESKTOP COMPUTER

by

Ricky Allen Foltz

June 1980

Thesis Advisor:

Matthew D. Kelleher

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Thermal Analysis and Design of Air Cooled Electronic
Circuit Boards Using a Desk Top Computer

by

Ricky Allen Foltz
Lieutenant Commander, United States Navy
B.S., Stanford University, 1971

Submitted in partial fulfillment of the
requirements for the degree of

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and
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June 1980

ABSTRACT

A thermal design procedure for air cooled electronic circuit boards has been developed for the Hewlett-Packard Model 9845 desktop computer. The system of interactive programs, called THERMELEX, performs thermal analysis of printed circuit boards to predict either the junction temperatures for given power dissipation levels or the maximum power levels for given junction temperature limits. The system includes the following features: totally interactive with all input in question and answer format, simple data verification and correction capabilities, ability to store and retrieve circuit board descriptive data totally under program control, wide variety of output formats including tabular and graphical. By using internal selection of heat transfer correlations, the THERMELEX system depends only on input of physical parameters for thermal predictions.

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NONMENCLATURE

Aair	Average area for cooling air flow	[m ²]
Agap	Area of bottom of component	[m ²]
Rl	Area for conduction in either a CPU or a circuit board lead	[m ²]
Apara	Area of the component experiencing parallel flow	[m ²]
Areg	Area of the region on the circuit board	[m ²]
Aspin	Surface area of the component lead	[m ²]
Astag	Area of the component experiencing stagnation flow	[m ²]
Axpin	Crossectional area of the component lead	[m ²]
Bdh	Height of circuit board (perpendicular to air flow)	[m ²]
Bdl	Length of circuit board (parallel to air flow)	[m ²]
Cpair	Heat capacity of the air	[J/Kg-degK]
CPU	Conduction Path Unit (size defined by user)	
Dgap	Distance between the component bottom and the circuit board	[m ²]
Dh	Hydraulic diameter	[m ²]
DIP	Dual Inline Package	
Epsb	Emissivity of the circuit board	
Epsc	Emissivity of the component	
Fair	Volumetric air flow rate	[m ³ /sec]

Fr	Roughness factor	
Gnu	Kinematic viscosity of air	[m ² /sec]
Gz	Graetz number	
Havg	Average height of the components present on the board	[m]
Hb	Heat transfer coefficient for the circuit board	[Watt/m ² -degK]
Hduct	Heat transfer coefficient for the duct formed by the circuit boards and equipment case	[Watt/m ² -degK]
He	Height of the component	[m]
Hpara	Heat transfer coefficient for areas receiving parallel air flow	[Watt/m ² -degK]
Hr	Dimension of region in the vertical direction or vertical distance between finite difference nodes	[m]
Hstag	Heat transfer coefficient for areas receiving stagnation air flow	[Watt/m ² -degK]
Kair	Thermal conductivity of cooling air	[Watt/m-degK]
Kb	Thermal conductivity of the circuit board	[Watt/m-degK]
Kl	Thermal conductivity of the board leads	[Watt/m-degK]
Kpin	Thermal conductivity of the component lead	[Watt/m-degK]
Le	Length of the component	[m]
Lpin	Length of component lead	[m]
Lr	Dimension of region in the horizontal direction or horizontal distance between nodes	[m]
Mair	Mass flow rate of cooling air	[Kg/sec]
Navg	Average number of component in a vertical column perpendicular to the air flow direction	

Npin	Number of leads on a component	
Nxr	Number of regions in the air flow of horizontal direction	
Nyr	Number of regions perpendicular to the air flow direction or vertical direction	
Perim	Wetted perimeter of the air duct	[m]
Pow	Energy dissipated in the component	[Watts]
Pr	Prandtl number	
Q	Rate of heat transfer	[Watts]
Oe-b	Total rate of heat transfer from the component to the circuit board	[Watts]
Q ₁	Total rate of heat transfer out the bottom of a circuit board region	[Watts]
Q ₂	Total rate of heat transfer out the right side of a circuit board region	[Watts]
Q ₃	Total rate of heat transfer out the top of a circuit board region	[Watts]
Q ₄	Total rate of heat transfer out the left side of a circuit board region	[Watts]
R	Thermal resistance for heat transfer	[deg K/Watt]
Re	Reynolds number	
Rb-conv	Total thermal resistance for convection from circuit board surface to the cooling air flow	[degK/Watt]
Rb-hor	Thermal resistance for conduction in the circuit board between nodes in the horizontal direction	[degK/Watt]
Rb-ver	Thermal resistance for conduction in the circuit board between nodes in the vertical direction	[degK/Watt]
Re-conv	Total thermal resistance for convection from component surface to the cooling air flow	[degK/Watt]

Rgap-cond	Conductive thermal resistance for the air gap between the component bottom and the circuit board	[degK/Watt]
Rgap-rad	Effective thermal resistance for radiation from the component bottom to the circuit board	[degK/Watt]
Rl	Total conductive resistance between finite difference nodes (centers of region)	[degK/Watt]
Rpara	Thermal resistance for heat transfer from area receiving parallel air flow	[degK/Watt]
Rstag	Thermal resistance for heat transfer from area receiving stagnation air flow	[degK/Watt]
Rtop-r	Effective thermal resistance for radiation from the top of the component to next board	[degK/Watt]
Rtote-b	Total thermal resistance between the component bottom and the circuit board	[degK/Watt]
Tair	Local air temperature	[degC, degK]
Te	Temperature of the component surface	[degC, degK]
Tb	Temperature of the board surface	[degC, degK]
Thb	Thickness of the circuit board	[m]
Tj	Temperature of the component junction	[degC, degK]
Vair	Velocity of the cooling air	[m/sec]
Wavg	Average width of the components present on the board	[m]
We	Width of the individual components	[m]
X	Direction parallel to cooling air flow also referred to as the horizontal direction due to orientation of circuit board picture on screen of computer	

Xi	Distance from the entrance of the cooling air	[m]
Y	Direction perpendicular to cooling air flow also referred to as the vertical direction due to orientation of circuit board picture on screen of computer	
Zb	Distance between circuit boards	[m , mm]

I. INTRODUCTION

A. BACKGROUND

Electronic components generally convert a significant fraction of the input power into internal joulian heating. When the components are large, widely separated, and air is permitted to circulate freely among them, this heat generated within the component is transferred to the environment through natural convection. Indeed, millions of pieces of home electronic equipment have operated reliably for years depending only on natural circulation for cooling. The major emphasis over the last 15 years has been a continuing effort toward a reduction in physical size of components and increased component density within electronic equipment. The military is particularly in need of smaller, more complex, yet reliable equipment that must often be sealed from an extremely hostile environment. This results in the need for more efficient cooling methods.

The age of large scale integration (LSI) is here. Although the power dissipated in each active junction within a component has greatly decreased, the large number of heat sources on each chip has created serious heat removal problems. There is a genuine need for electronic designers to not only be aware of the problems associated with higher

temperatures, but they must also be prepared to solve those problems. References [1] through [10] are a sampling of the many sources that indicate the increased emphasis on cooling problems throughout the electronics community.

The need to operate electronic equipment with maximum junction temperatures below those levels that result in failure is well recognized, but even moderately high temperatures in electronic components result in progressive deterioration and reduced reliability. A generally accepted thumb rule is: for every 10 deg C increase in junction temperature, the lifetime of a component will decrease by one-half. [3, 7] The increasing costs associated with each failure make it imperative to address reliability during the equipment design phase and to provide sufficient cooling to maintain temperatures as low as practical.

There are many methods of removing the heat dissipated within electronic components. These methods include the natural air convection previously mentioned, thermo-electric devices, heat pipes, cold plates and even complex refrigeration systems which use pumped liquid coolants [8]. The complex systems required for these solutions can lead to lower reliability through increased probability of failures in the cooling system. While many of these methods can allow extremely high power densities for specific applications, the most widely used method for cooling of components

mounted on printed circuit boards is forced air cooling. Air is readily available, abundant, non-corrosive, non-toxic, non-flammable, dielectric, and is easily pumped using readily available fans and blowers. For those situations where there is a need to seal the equipment, interior cooling air is often circulated through heat exchangers.

All too often the problem of cooling the electronic components is attacked after the circuit boards have been designed or even produced and assembled [9]. In some cases, the need for increased cooling is recognized only after repeated failures in service have resulted in unhappy users and excessive repair costs. At best both the electronic design and the thermal design progress concurrently but are worked on by separate design groups. These groups may have conflicting range goals that can interfere with the important long range goal of reliability.

Many of the efforts to directly involve the electrical designer in the thermal problems are directed towards overall system cooling. Reference [11] details a thermal design program called VENTBOX. VENTBOX treats a cabinet enclosure with entire circuit boards modeled as distributed heat sources. This program fails to address the problems of individual components and, therefore, is unable to analyze the circuit board.

Electronic circuit analysis programs are often utilized in the thermal analysis of circuit boards [12 and 13]. This

technique requires the development of an equivalent thermal circuit, usually by a packaging engineer, and thus the thermal design is removed from the hands of the electronic designer. Reference [14] details a thermal analysis program for circuit boards that is much more accessible to an electronic designer since the inputs are physical dimensions and types of components rather than equivalent thermal network parameters.

All these programs share a major weakness in that they depend on a large general purpose computer facility. This not only can result in excessively long turn-around times in batch processing, but also the expense of computer time may become a factor. In addition, the input data typically consists of long lists of numbers that must be in the proper format with the correct option selection codes. Likewise the output also consists of even longer lists of numbers with the key information hidden in their midst.

One solution to automated thermal design and analysis of avionics systems is being developed as a joint project by the Air Force Flight Dynamics Laboratory at Wright Patterson Air Force Base and Boeing Aerospace Company. The ITAD (Integrated Thermal Avionics Design) system is expected to include many existing analysis programs and a large ever growing data base containing reliability parameters. It is anticipated that ITAD will be accessed by user through both batch methods and interactively through color graphics

terminals. The scope of this project is enormous and the benefits to the system designer will be many, provided he has access to the large computer at Wright Patterson Air Force Base [15, 16].

Another solution on a much smaller scale is to create a program for a compact, stand alone desktop computer that is easily accessible to the designer of electronic circuit boards. Such a system, if interactive and "friendly" to the casual user, would allow rapid evaluation of various circuit board designs at the conceptual level. Rejection of those designs with poor thermal characteristics could then occur before they leave the drafting table saving both future efforts and dollars.

B. OBJECTIVES

The main objective of this thesis was to develop an interactive thermal analysis program utilizing the Hewlett-Packard 9845 desktop computer. It was considered important to include the following features:

1. Simplicity of operation: All data input and control of program flow are done in a question and answer format including specific instructions with each question.
2. Graphical data checking: Display circuit board replicas on the screen both for verification of input and to provide a more useful form of output.

3. Data correction capabilities: Use interactive methods to allow correction of portions of the data without the need to repeat all the input.

4. Automatic storage and retrieval of data: Circuit board descriptions should be written to and read from mass storage devices using simple questions and answers rather than requiring specific knowledge of operations of the devices.

5. Analysis methods hidden: Various empirical heat transfer correlations should be used based on the physical descriptions and the user should be relieved of the need to make decisions concerning the details of the heat transfer analysis methods.

6. Sensitivity analysis: Allow automatic parameter changes to investigate the effects on the thermal performance of these changes with plotted data.

II. DESCRIPTION OF THE THERMELEX SYSTEM

A. GENERAL

1. The Computer

The name THERMELEX will be used to refer to the system of interactive programs created to perform thermal analysis of air cooled electronic circuit boards. The programs are written for the Hewlett-Packard Model 9845 desktop computer using the Hewlett-Packard extended version of the basic language. A sophisticated operating system hides the complexity of the 9845 from the user and provides protection from his mistakes yet provides the power and flexibility needed for application programs such as the THERMELEX system.

The computer used to create and debug THERMELEX is the 9845A with 64 k bytes of read/write memory (option 203), internal printer (option 500) and graphics package. In addition, dual tape drives and dual floppy disks were utilized in the development of the system. These additional mass storage devices provided considerable increase in the convenience and speed of storage and retrieval operations but THERMELEX is designed to operate with only the standard tape drive. Recent advances in the internal electronics have resulted in this model being superseded by the 9845B model with larger memory capabilities and several other features.

THERMELEX is available in either an A-version or B-version for use in the respective model of the 9845.

Figure 1 shows the 9845A but the 9845B is identical in physical appearance except for the name tag. The screen at the top will display the messages from the system to the user, what is typed by the user and the output from the THERMELEX programs. This output may be printed on the screen in what is known as the alpha mode or it may be presented as pictures and words from the graphics mode. Output of either mode may also be produced on the thermal printer above the keyboard in the inclined area. Directly underneath the screen there are four pull-out reference cards that explain error messages and other operating conditions that may occur. At the extreme upper right corner of the sloping section is the standard tape transport (:T15) for mass storage of programs and data.

The keyboard contains not only a set of standard typewriter keys but also several other groups of keys that are important to THERMELEX. The numeric keys at the lower right allow easy entry of numbers as an alternative to those in the alphanumeric group of keys and allows numeric calculations to be performed even during execution. Between these groups are the gold colored program control keys. All responses to questions are followed by pressing the CONT key at the bottom of this column of keys. The group of special

function keys in the upper right are defineable by the user or from program control. They are also used in THERMELEX as priority interrupts to simplify the input of data. This use of these keys is further explained later. The final key of interest to the THERMELEX system user is the AUTOST key in the lower right corner of the EDIT/SYSTEM FUNCTIONS group. This key allows automatic loading and execution of the first program in the THERMELEX system. Explanation for its use is found in Appendix 1, the User Instructions. For further explanations of the features of the Hewlett-Packard model 9845 computer, see Ref [17] supplied with the computer.

2. THERMELEX System

Due to the memory limitations of the 9845A, THERMELEX is divided into three major programs which are generally brought into case from mass storage under program control as they are needed. However, each program is designed to stand alone which can allow the experienced user to bypass some of the questions and answers required to help the inexperienced users. AUTOST is the first program of the three; here several pages of user instructions (see Appendix 1) may be printed, the special function keys are defined and the user is directed along a path to follow towards the other programs. In BOARDS, the circuit board descriptive data is entered, verified and stored on any one of the mass storage devices. The user may also elect to produce a printed copy of the input data for

his records. The THERML program performs the thermal analysis and provides output in various tabular or graphical forms. These three major programs will be described in more detail in the pages that follow.

There are also several smaller files in the system. BDSKEY and STDKEY alter the definitions of the special function keys. TNAMES contains a listing of all variable names and program section names with explanations to aid in any future modifications of the THERMELEX system. DEMO-P and DEMO-T are data files containing example circuit board descriptive data to allow demonstrations of the system and to help the new user become familiar with the capabilities.

B. AUTOST

1. General

AUTOST is the driver program for the system. This name allows the program to be automatically loaded and executed if the AUTOST key is latched down and if the tape containing the THERMELEX system is in the standard right-hand tape drive (:T15) when the main power switch is turned on. Regardless of how the program is loaded, the first question will be concerning the location of THERMELEX. The program will ask which mass storage device contains the system since this is necessary for correct program control. At this point, the program defines the default mass storage device using the "MASS STORAGE IS "---" command, and the

default mass storage device should not be altered while using THERMELEX.

2. Instructions

AUTOST will provide a printed set of user instructions either on the screen in short segments or on the thermal printer in 8.5 by 11 inch pages. These instructions present an overall system view and are intended to familiarize the inexperienced user and supplement the extensive instructions and prompts that are presented on the screen in all sections of THERMELEX.

3. Special Function Keys

AUTOST redefines the special function keys as required for the system and can provide a paper key-code overlay as a substitute for the plastic model (Hp Part #7120-6164). Figure 3 shows both styles. The paper style may be used as a guide for filling in the appropriate blanks on the plastic version.

4. Option List

Finally, AUTOST provides a list of options for the user to select from. He may load either of the other two programs in THERMELEX or produce a complete copy of the programs in the system through selection of the appropriate number from the menu of options. This technique is employed throughout the system whenever possible because of the simplicity involved in entering a single number over other methods of option selection.

5. The Copy Option

The copy option is included as a built-in feature since there are many separate files in THERMELEX and a separate command is required for each file to be copied. Any mass storage device may serve as the destination for the system; however, when copying to tape, it is suggested that it be blank due to the number of open blocks required. Following completion of this option, program control returns to option list. It is expected that the first option (keyboard entry of circuit board description) is the most likely to be used and the description that follows assumes this path.

C. BOARDS

1. General

The major purpose of the BOARDS program in the THERMELEX system is to provide a simple method for input of the descriptive data needed in THERML for the creation of the thermal model and the analysis. This data includes the geometric and material properties of the circuit board as well as what components are on the circuit board. These components are limited to DIP's (Dual Inline Packages) and chip carriers (FLAT Packs). The thermal model used for the analysis of the board is a finite difference scheme and the physical location of the components is approximated by the locations of the finite regions created by the user.

The descriptive data may be entered from the keyboard in response to simple questions; or, it may be retrieved from mass storage data files previously recorded using BOARDS. The instructions included as Appendix 1 provide specific explanations of how to use this program.

2. Checking of Input Data

All input data is displayed using either the graphics capabilities of the 9845 or with printed lists produced on the screen or paper. The user may, therefore, easily verify the validity of the data he has entered. This feature is included whenever possible throughout THERMELEX.

3. Correction of Input Data

There are many opportunities to change the descriptive data using the same question and answer format of interactive programming. At no time is it necessary for the user to have extensive knowledge of the program's internal workings or the machine level commands performed within the program. As a further means of correcting past errors, the backup feature built into the THERMELEX system makes it extremely easy to return to previous questions. This feature is accessed by depressing the special function key (Ko) in place of a response to a request for input. Program control will jump back to the previous question to allow re-entry of data. Repeated use of Ko allows backing up to any desired point and resumption of program flow from that point.

4. The Circuit Board

To describe the geometry of the circuit board under investigation, the user must enter the length, width, thickness and the thermal conductivity of the circuit board. With no input, the thermal conductivity will be assigned a default value of 0.29 Watts/m-degC, a representative value for the bonded glass laminates generally used for construction of circuit boards. The length parameter is defined to be in the direction of air flow regardless of which dimension is the largest.

In order to create the finite difference thermal model, the board must be divided into logical regions by placing any number of equally spaced vertical lines and any number of equally spaced horizontal lines on the board up to a total of 50 regions. More regions would be possible in the 9845B due to the larger memory capacity but this would require some program changes. Each region will either contain a component assumed to be centered in the region or will be empty. Since there may be regions with no components, there is no unique set of descriptive data for a given circuit board design. The user is encouraged to try different combinations of horizontal or x regions and vertical or y regions to describe a circuit board. Figure 4 shows two such possibilities for a board with six 14 pin DIP's. Both the six region model and the 42 region model describe the same board. Experience is helpful in making decisions as

to how to divide the board and some boards may not fit into the constraints imposed by THERMELEX, but many will.

5. The Components

Each of the defined regions will be empty or contain one of the following components: 14, 16, 24, 40 pin DIP's with either vertical or horizontal orientation and 16, 24, 40, 64 pin chip carriers. These components will be assumed to be centered in the region (with the exception of the 40 pin DIP which will be assumed to occupy two regions). The input of component type for each region is via the special function keys. A special paper key-code overlay for use in this component input section may be provided if a plastic version is not available, see Figure 5. As a flashing cross appears in each of the regions, the appropriate special function key is depressed. This defines the type of component, length, width, orientation and draws the component on the screen for visual verification of corrections. After all regions have been defined, corrections are possible through removal and replacement of components using the same special function keys.

6. Thermal Conduction Paths

Each of the defined regions on the board may exchange energy with the adjacent regions via conduction through the board itself and any thermally conductive material added to the board such as electrical leads. In addition, many circuit

board designs involve metal conduction rails that provide both mechanical support and a method to transport the heat from the componets. There are provisions in BOARDS to model either the electrical leads or the conduction rails. For circuit boards without conduction rails, the user specifies the average lead width (mm), thickness and thermal conductivity of the lead material. These geometric parameters are used to determine the thermal resistance of a single lead connecting the region centers or nodes.

When conduction rails are included on the circuit board, the effects of the electrical leads are ignored. To allow modeling of rails that may have different widths, the concept of a conduction path unit (CPU) is introduced. A CPU is defined to be .1 mm in width but the user specifies the thickness and conductivity of the material. These parameters are used to determine the thermal resistance of a single CPU connecting the region centers.

With the thermal resistance of single CPU or electrical lead determined, the user need only specify the number of such resistances that connect the circuit board regions. For example, if a conduction rail is 5.8 mm in width, it may be modeled as containing 58 CPUs. While the concept of CPUs is totally artificial, this concept does allow modeling of the Navy Standard Electronic Module (SEM) and Improved Standard Electronic Module (ISEM) for those situations when these modules are used in forced air cooled systems.

With the physical description of the circuit board now complete, the user may elect to produce a picture of the circuit board from a dump of the graphics to the internal printer. Pressing special function Key 3 will produce a picture such as Figure 6. This picture may be used as a final verification of the validity of the circuit board description that has been entered. The remaining descriptive data to be entered concerns the component parameters.

7. Temperature or Power Input

The user must specify either the average power to be dissipated in each component or the maximum junction temperature. When power levels are specified, the steady state junction temperatures will be calculated in THERML. When junction temperatures are specified, the maximum allowable component power levels will be calculated. In either case, the user must also specify a case to junction thermal resistance for each component. This is usually supplied by the manufacturer and provides the means in the thermal model to link the component power level and junction temperature to the case surface temperature. Figure 7 shows the data summary sheet provided after the data has been entered and verified.

8. Storage of Data

Although it is possible to load THERML and perform the thermal analysis directly since all data is passed

through a common block, it is strongly urged that the circuit board description be stored on mass storage. A few simple answers allows the storage to tape or disk for retrieval at a later time. This data file may be accessed, verified, altered and recorded back to mass storage using BOARDS to investigate the effects that changes in design have on the temperatures or power levels obtained in THERML. Both Appendix 1 and the program provide easy to follow instructions for retrieval of previously recorded descriptive data files.

Totally under program control, the third major program in the THERMELEX system, THERML will be loaded at the direction of the user and execution started at the proper entry point.

D. THERML

1. General

Recall from the previous discussion that BOARDS establishes all the parameters that describe the circuit board. While the major purpose of THERML is to analyze the thermal performance, it must first establish the parameters that describe how the circuit board is installed and cooled, such as the spacing between boards, volumetric air flow per board and inlet temperature of the cooling air. Using the total set of board and installation parameters, the thermal model is set up, solved and the results presented.

The approach taken in the thermal analysis is to construct an approximate thermal network [7] for every path

of heat transfer from the components and the circuit board. The thermal resistance (R) for each path is calculated from the set of parameters and if a temperature difference (ΔT) for that path is known, the expression:

$$Q = \frac{\Delta T}{R}$$

will determine the rate of heat transfer (Q) for that path. When the rate of heat for a given path is known, the expression:

$$\Delta T = (Q) \times (R)$$

will determine the temperature difference.

An overall heat balance for the components and the circuit board, with all the heat that is generated going into the cooling air stream, is used to determine either the steady state junction temperatures (when component power levels are specified) or the component power levels (when the junction temperatures are specified).

2. Air Flow - Thermal Model

The cooling air flow is assumed to come from an infinite heat sink which supplies air at a constant inlet temperature. All the heat dissipated within the components is assumed to enter the air stream with no heat conducted into the card guides or electrical connectors. These guides and the mechanical support sections of the connectors are typically made of plastic with high resistance to heat transfer and this assumption leads to conservative estimates.

As the air travels from inlet to outlet, it is assumed to remove heat from both the component surfaces and the surface of the circuit board. It is further assumed to travel in air lanes defined by the height of each region perpendicular to air flow and not mix until the outlet. As the air removes heat from each region, the local air temperature (T_{air}) will increase. The process is described by the general equation:

$$- \quad T_{air} \text{ at } X + \Delta X = T_{air} \text{ at } X + \frac{Q \text{ added in } \Delta X}{(M_{air}) \times (C_{pair})}$$

where M_{air} = Mass flow rate of air [kg/sec]

C_{pair} = Heat capacity of air [J/kg-degk]

ΔX = length of a region in the air flow direction

This process results in the temperature of the cooling air stream being modeled as a series of steps as the air travels from inlet to outlet within an air flow lane. The local air temperature and the convective resistance determine the local convective heat transfer.

The air velocity is determined from the physical description entered by the user and this air velocity is used to determine the convective resistances. Recall that circuit board spacing (Z_b), board height (H_b) and volumetric air flow rate (F_{air}) are part of the descriptive data set previously entered. With no components present, the air velocity (V_{air}) would be defined by:

$$V_{air} = \frac{F_{air}}{(Z_b) \times (H_b)}$$

However, the components tend to reduce the air flow area (A_{air}) by blockage. The average blockage area is determined by calculating the average number of components in a vertical column of regions perpendicular to the air flow. In addition, the average width (W_{avg}) and height (H_{avg}) of the components is determined and the average air flow area calculated using:

$$A_{air} = (Z_b) \times (H_b) - (N_{avg}) \times (H_{avg}) \times (W_{avg})$$

This area is used to determine the air velocity from:

$$V_{air} = \frac{F_{air}}{A_{air}}$$

In addition the average area is used to determine the wetted perimeter ($Perim$) of the air duct formed by the boards according to:

$$Perim = 2H_b + 2Z_b + 2 (N_{avg}) \times (H_{avg})$$

The hydraulic diameter (D_h) is therefore:

$$D_h = \frac{4 A_{air}}{Perim}$$

which is also used in calculations of some of the heat transfer coefficients.

3. Components - Thermal Model

All heat generated within the components must be transferred away through conduction to the board, radiation to the board and to some radiation sink, and through convection to the cooling air. Figure 8 shows each of the thermal networks for heat transfer.

DIP components are usually mounted by soldering the electrical leads to the circuit board electrical conductors (Figure 9). These connector pins also act as low resistance thermal conductors between the component and the circuit board. The total thermal resistance from the component to the circuit board may be calculated from the cross sectional area of each pin (A_{pin}), the length of the pin (L_{pin}), the thermal conductivity of the pin material (K_{pin}) and the number of pins (N_{pin}) using the expression:

$$R_{pin} = \frac{L_{pin}}{(K_{pin}) \times (A_{pin}) \times (N_{pin})}$$

There is also a small gap between the bottom of the component case and the circuit board. Figure 9 shows the mounting for DIP cases where this gap is on the order of one mm; for chip carriers, this distance is smaller yet. Due to the small distance (D_{gap}) involved, it is assumed that no convection occurs in this gap and that the conductive resistance of the air gap ($R_{gap-cond}$) may be calculated from the expression:

$$R_{gap-cond} = \frac{D_{gap}}{(K_{air}) \times (A_{gap})}$$

where A_{gap} represents the surface area of the bottom of the component and K_{air} represents the thermal conductivity of the air.

The component case will also radiate energy to the circuit board. Assuming the gap to act as two parallel

plates of equal areas with emissivities of ϵ_{psb} and ϵ_{pse} , the heat transfer rate may be calculated (Ref [18]) from:

$$Q = \frac{(\text{Sig}) \times (A_{gap}) \times (T_e^4 - T_b^4)}{\frac{1}{\epsilon_{psb}} + \frac{1}{\epsilon_{pse}} - 1}$$

where:

Sig = Stefan-Boltzman constant

$$(5.67 \times 10^{-8} \frac{\text{Watts}}{\text{m}^2 \cdot \text{degK}^4})$$

T_e = Component surface Temperature (degK)

T_b = Circuit board Temperature (degK)

This radiation term may be simplified by expanding $(T_e^4 - T_b^4)$ in a Taylor series about T_e and retaining only the linear portion of the series. When this is done, an effective gap radiation resistance ($R_{gap-rad}$) may be calculated from:

$$R_{gap-rad} = \frac{\epsilon_{pse} + \epsilon_{psb} - (\epsilon_{pse})(\epsilon_{psb})}{(r) \times (\text{Sig}) \times (\epsilon_{pse}) \times (\epsilon_{psb}) \times (T_e^3)}$$

Since the component case temperature (T_e) is an unknown, this resistance will be recalculated as the solution progresses.

These three resistances (R_{pin} , $R_{gap-cond}$, $R_{gap-rad}$) may be combined into a total resistance between the component and the circuit board (R_{tote-b}). When the component is a chip carrier, the air gap and lead length are assumed to be one-tenth that of the DIP case [13].

Although the radiation heat loss from the component is extremely small and normally neglected in thermal analysis of electronic circuit boards, it is included here for completeness.

The component will radiate to the other components and the back of the adjacent circuit board. For the purposes of the thermal model under discussion, it is assumed that radiation is from the top of the component to the adjacent board and that this adjacent board temperature is the same as the board temperature below the component. It is further assumed that the area of the circuit board is much greater than that of the component. Using the same linearization technique previously discussed results in the expression:

$$R_{top-r} = \frac{1 - \epsilon_{ps}}{(4) \times (\text{Sig}) \times (\epsilon_{ps}) \times (A_e) \times (T_e)^3}$$

for the effective thermal resistance for radiation from the top of the component to the adjacent circuit board.

Convection heat transfer to the air, the final heat loss path from the component, depends on the heat transfer coefficient and the area for that mode of heat transfer. The component is assumed to experience two separate modes of convection. Those portions of the component that are perpendicular to the air stream are assumed to experience a stagnation form of air flow while the top and sides see parallel air flow. Recall that air flow is defined as being from left to right as required for data entry in the BOARDS program. When component types are entered as being horizontal or vertical using the special function keys, the component length (L_e) and width (W_e) parameters are set such that L_e is along the air flow direction and W_e is perpendicular to

the air flow. The standard correlation for plane stagnation flow may be written as: Ref [19]

$$H_{stag} = (.57) \times (K_{air}) \times (Pr^{.4}) \times \left(\frac{V_{air}}{(We) \times (Gnu)} \right)^{\frac{1}{2}}$$

where H_{stag} = Heat transfer coefficient for areas receiving stagnation air flow

Pr = Prandtl number for air

Gnu = Kinematic viscosity for air

Using the component height (H_e), the area for stagnation heat flow (A_{stag}) may be calculated from:

$$A_{stag} = (2) \times (We) \times (H_e)$$

The portions of the component that are parallel to the air flow (top and sides) are assumed to experience the same heat transfer coefficient that would occur in a smooth duct modified by a roughness factor (Fr) to account for the presence of the components acting to increase this heat transfer coefficient (H_{para}). H_{para} depends on the Reynolds number (Re) determined by:

$$Re = \frac{(V_{air}) \times (D_h)}{Gnu}$$

In the entrance region of the duct formed by the circuit boards, up to a distance of approximately ten hydraulic diameters, the flow is assumed to be laminar. Reference [20] contains the following correlation for the heat transfer

coefficient in the entrance region of a smooth duct:

$$H_{duct} = \frac{(.664) \times (K_{air})}{(1.1) \times (D_h)} \left[\frac{(Gz) \times (1 + (7.3) \times (\frac{Pr}{Gz})^{\frac{1}{2}})}{Pr} \right]^{\frac{1}{2}}$$

where Gz is the Graetz number defined as:

$$Gz = \frac{(Re) \times (Pr) \times (D_h)}{Xi}$$

and Xi is the distance from the entrance of the cooling air flow.

The value of the heat transfer coefficient predicted from the above equation has been found to be low from comparisons to experimental data of Ref [12] and Ref [14]. The expression:

$$Fr = 1 + \frac{5 \times (Perim - (2) \times (B_{dh}) - (2) \times (Z_b))}{Perim}$$

has been created to adjust the predicted heat transfer coefficient for the rough duct. The expression reduces to one when no components are present and is less than two for all reasonable board constructions. The resulting heat transfer coefficient that is used for the parallel sides (H_{para}) is therefore:

$$H_{para} = (H_{duct}) \times (Fr)$$

For positions beyond the entrance length the flow may be laminar or turbulent and the appropriate heat transfer correlation must be chosen. The transition from laminar to turbulent is assumed to occur at a Reynolds number of 1000

since the components act as turbulence promoters for the air flow. For laminar flow, the expression:

$$H_{duct} = \frac{(5.4) \times (K_{air})}{D_h}$$

is used and the result modified with the roughness factor (Fr) to obtain H_{para} . For turbulent flow the Dittus-Boelter relationship is used:

$$H_{para} = \frac{(.023) \times (Re^{.8}) \times (Pr^{.4}) \times (K_{air})}{D_h}$$

Heat is convected not only off the top and sides of the components but also from the surface of the leads or pins. Since the thermal conductivity of the pin material is so high, their surface is assumed to have the same temperatures as the surface of the component. The effective component parallel side area for heat transfer is, therefore, determined from:

$$A_{para} = (L_e) \times (W_e) + 2(L_e) \times (H_e) + (A_{spin}) \times (N_{pin})$$

where A_{spin} is the surface area of the pins that experience parallel air flow. The thermal resistances for convection from the component may then be calculated from:

$$R_{para} = \frac{1}{(H_{para}) \times (A_{para})} \quad \text{and,}$$

$$R_{stag} = \frac{1}{(H_{stag}) \times (A_{stag})}$$

These two resistances may then be combined as parallel resistances to give a total convective thermal resistance from the component to the air (Re-conv) of

$$Re\text{-}conv = \frac{(R_{para}) \times (R_{stag})}{(R_{para}) + (R_{stag})}$$

Returning now to the basic premise that all the heat produced within the component must be transferred through one of the heat paths illustrated in Figure 8, the heat balance equation for the Ith component is:

$$Pow(I) = Q_{to \text{ board}} + Q_{to \text{ air}} + Q_{rad \text{ off top}}$$

utilizing the general expression for heat flow as a function of temperature difference. This may be expressed as:

$$Pow(I) = \frac{Te(I) - Tb(I)}{R_{ToTe-b(I)}} + \frac{Te(I) - Tair(I)}{Re\text{-}conv(I)} + \frac{Te(I) - Tb(I)}{R_{top} - R(I)}$$

This expression may be rearranged and solved for the component temperature (Te). The resulting expression is used to eliminate Te from the final set of equations that are solved for the set of board temperatures.

4. The Circuit Board - Thermal Model

The circuit board has been divided into regions as determined by the user while entering the circuit board description in program BOARDS. Each of the regions will lose or gain heat by the normal processes of conduction,

convection and radiation. In this thermal model, radiation from the circuit board regions is neglected due to the lower temperatures of the circuit boards. The board temperature (T_b) is assumed to be uniform within a given region for purposes of convective heat transfer to the cooling air stream. For purposes of calculating the heat conducted between regions, the temperature differences are assumed to exist over the distance between the centers of the regions. These region centers are the nodes in the finite difference model used to analyze the circuit board.

The surface of the board forms part of the air duct previously mentioned in the discussion concerning the calculation of the convective heat transfer coefficient from the parallel sides of the components (H_{para}). The heat transfer coefficient of the board varies with distance from the air centered in the regions, the convective heat transfer coefficient for the board (H_b) is assumed to be equal to H_{para} . The area for heat transfer from each region (A_{reg}) includes both sides but excludes any area under the component (A_e) since the air is assumed not to flow in the small gap between the component and the circuit board. The area (A_{reg}) is calculated from the equation:

$$A_{reg} = \frac{(2) \times (Bd1) \times (Bdh)}{N_{reg}} - A_e$$

where $Bd1$ = Length of circuit board

Bdh = Height of circuit board

The convective resistance from the circuit board region (R_{b-conv}) is therefore:

$$R_{b-conv} = \frac{1}{(H_b) \times (A_{reg})}$$

The conduction of heat within the circuit board material and any added conductive material is assumed to occur between the nodes located at the centers of each region. For a given region, this heat flow is assumed to occur only out the four sides of the region. The distance between nodes in the horizontal or air flow direction (L_r) is calculated from the circuit board length (B_{dl}) and the number of regions in the horizontal direction (N_{xr}). The expression used is:

$$L_r = \frac{B_{dl}}{N_{xr}}$$

Likewise, the vertical spacing between nodes (H_r) is calculated as:

$$H_r = \frac{B_{dh}}{N_{yr}}$$

These distances are used with the circuit board thickness (T_{hb}) and the circuit board material thermal conductivity (k_b) to determine the base board conductive resistances in both the vertical (R_{b-ver}) and horizontal direction (R_{b-hor}). The expressions used are:

$$R_{b-ver} = \frac{H_r}{(k_b) \times (L_r) \times (T_{hb})}$$

and

$$Rb-hor = \frac{Lr}{(kb) \times (Hr) \times (Thb)}$$

The conductive resistances in the material added to the circuit board is treated in the same manner since these materials are also assumed to connect the nodes. The conductivity of the material (k_l) and physical area (a_l) have been specified for either a conduction path unit (CPU) or electrical lead. These are used in the expressions:

$$Rl-ver = \frac{Hr}{(k_l) \times (A_l)}$$

and

$$Rl-hor = \frac{Lr}{(k_l) \times (A_l)}$$

to determine the thermal resistance for conduction in a single conduction path. This resistance is divided by the number of such paths to determine the total conductive resistance of the material added to the circuit board.

This resistance is assumed to be in parallel with the conductive thermal resistance of the bare circuit board and a net conductive thermal resistance is calculated for each of the four directions using a normal product-over-sum formula for parallel resistances. Figure 10 shows how a typical region would thus be connected to the four adjacent regions. The values of these conductive thermal resistances are stored in a two dimensional array, $R_l(I,J)$, where the

first index represents the region number and the second index is the direction number (1, 2, 3, 4). These numbers represent bottom, right side, top, and left side, respectively. For example, Figure 10 shows how $R_1(I,2)$ connects region number I and region number $I + 1$. For those regions on the edges of the circuit board, the conductive thermal resistance in the direction off the board are set to very high value due to the assumed adiabatic boundary conditions for all edges. The set of conductive thermal resistances, $R_1(I,J)$, is used in the heat balance for the circuit board.

With the component treated as the source of heat for the circuit board, one may again apply a simple heat balance for a region as follows:

$$Q_{e-b} = Q_{conv} + Q_1 + Q_2 + Q_3 + Q_4$$

where Q_{conv} represents the heat transfer to the cooling air and Q_1 through Q_4 represent the heat conducted to the adjacent regions as shown in Figure 10. This expression may be written for Region I as:

$$\begin{aligned} \frac{T_e(I) - T_b(I)}{R_{tot-a-b}} &= \frac{T_b(I) - T_{air}(I)}{R_b-conv} + \frac{T_b(I) - T_b(I + N_{xr})}{R_1(I,i)} \\ &+ \frac{T_b(I) - T_b(I + 1)}{R_1(I,2)} + \frac{T_b(I) - T_b(I - N_{xr})}{R_1(I,3)} \\ &+ \frac{T_b(I) - T_b(I - j)}{R_1(I,4)} \end{aligned}$$

As previously stated, the heat balance equation for the component derived in Section 3 may be solved for $T_e(I)$ and that expression

used to eliminate $T_e(I)$ from the equation above. The only unknowns will then be the board temperatures. A heat balance for every region may be performed resulting in N_{reg} simultaneous algebraic equations. The coefficients of these equations may then be collected into a matrix and solved using an LU decomposition method [21].

5. The Analysis

In performing the thermal analysis of the circuit board, there are two separate situations to be considered:

1. Specified component power - determine steady state junction temperature;
2. Specified junction temperature - determine the maximum power allowable.

For the first situation a case temperature (T_e) is assumed for each component since this is necessary to determine the effective radiation resistances. All thermal resistances and the local air temperatures are then calculated using the given variables. The resulting system of N_{reg} simultaneous equations is solved using LU decomposition for the temperature of each region of the circuit board T_b .

This set of board region temperatures is used to determine the set of component case temperatures using the expression for T_e determined from the heat balance of the component. These component temperatures are compared to those from the previous iteration. If the largest difference between any of the temperatures is less than the convergence criterion established by the user (default .1 degC), the

results are presented in the graphics mode on a facsimile of the circuit board as shown in Figure 11.

In the display of the circuit board, each region contains the component type, junction temperature, power level and case temperature for the component in that region. Empty regions contain only the temperature of the circuit board. Those junction temperatures that are within 5% of the maximum are starred (**) for easy reference. This output is dumped to the internal thermal printer to provide a hard copy.

If convergence has not been reached, the new case temperature is used to calculate new radiation thermal resistances and the new system of equations solved. Figure 12 shows the intermediate display of all temperatures that is presented on the screen while the next iteration is in progress. If longer than 20 lines, the maximum display area for output on the screen, this display may be moved up or down with the display control keys at the center top of the keyboard (see Figure 2). Convergence typically occurs in less than four iterations when solving for component junction temperatures.

For the second situation with specified junction temperatures (T_j), a power level of .25 watts is assumed for each component. The component case temperature may then be determined from the expression:

$$T_e = T_j - \frac{P_{ow}}{R_{j-c}}$$

where R_{j-c} represents the case to junction thermal resistance set by the user. As in the first situation, all the thermal resistances and the local air temperatures (T_{air}) are calculated. It is important to note that T_{air} depends on the assumed power levels since these values will change with each iteration. The resulting system of simultaneous equations is again solved for the board region temperatures and the component case temperatures. The resulting component power levels for each region are determined from the expression

$$Pow = \frac{T_e - T_b}{R_{tote-b}}$$

This component power level for each component is compared to the results of the previous iteration or the assumed values for the first iteration. Convergence is assumed when the largest percentage difference from these comparisons is less than the convergence criterion established by the user (Default 1%).

The output is presented in the same manner as before except those power levels within 5% of the minimum are starred (**) in this situation (Fig. 13). Since both the radiation thermal resistances and local air temperatures depend on the power levels, more iterations are required before convergence is reached. Typically less than six are sufficient.

6. What Now Option List

Following a complete cycle through THERML, there are several options available to the user. A different circuit board may be analyzed either by entering the descriptive data set from the keyboard or by retrieval from mass storage. The previously recorded data set may be read in using THERML with no data checking capabilities or BOARDS may be loaded under program control to allow data checking or changes to the circuit board.

In addition the same circuit board may be reanalyzed with a new set of installation parameters, i.e., board spacing, inlet air temperature and volumetric air flow rate per board.

7. Sensitivity Analysis

Another option available allows the user to investigate the effects of various air flow rates. The user specifies a maximum air flow rate and five separate analyses are performed for each of five air flow rates up to the maximum specified. Figure 14 shows how the results of this sensitivity analysis are presented for the situation of specified power levels while Figure 15 is an output for the second situation of specified junction temperatures. The outputs from each analysis such as Figures 11 and 13 are not presented during the sensitivity analysis since the graphics mode is used but an output such as Figure 12 may be presented on the thermal printer if records of individual components are needed for each of the separate air flow rates.

A final option available to the user is termination. It is important to terminate the THERMELEX system under program control to insure normal key definitions are returned and graphics parameters correctly assigned.

III. RESULTS AND CONCLUSIONS

The THERMELEX system offers the designer of electronic circuit boards the means to predict the thermal performance of air cooled circuit boards and avoid the problems that often surface only after the equipment is in use. The system is easy to use yet provides valuable data in a variety of formats that can help the designer to make important design decisions regarding circuit board layout and/or cooling air flow parameters.

The THERMELEX system has been tested with a wide variety of circuit boards to insure that various combinations of the possible components and empty regions will create valid descriptive data sets and reasonable results. In all test cases the results have been satisfactory when compared to expected results. For example, higher component power levels result in higher junction temperatures and decreasing air flow produces higher temperatures with all else the same. Several tests were made that used the results of a power level prediction as input to the same circuit board to insure that predicted junction temperatures were the same as those specified for the original test.

In addition to the above tests for general validity, direct comparisons to experimentally determined component

case temperatures reported in reference (14) were made. The circuit board consisted of 25 equally spaced 14 pin DIPs and is depicted in Figure 6. Three different air flow rates and four different component power levels were used. The results of these experiments are shown in Figure 16. These same flow rates and power levels were used as inputs for THERMELEX and the predicted maximum case temperatures are also included in Figure 16. At the lower power levels, the agreement with the experimental results is encouraging but for the higher power levels there are significant differences. In particular, the predicted maximum case surface temperature shows a much stronger dependence on the air flow rate than the experimental results would indicate. It is believed that several effects neglected in the the thermal model become significant for low flow rates and higher component power levels. For low air flow rates, the effects of natural convection heat removal become more important, thus decreasing the actual surface temperature. In addition, at higher temperatures, the conduction into the electrical connectors and mechanical supports will also tend to hold the surface temperatures lower for the experimental results. Further work is needed to resolve the differences between the experimental results and those predicted by THERMELEX. Particular attention towards refinement of the thermal model is required.

IV. RECOMMENDATIONS FOR FUTURE WORK

While the present version of THERMELEX can be a valuable tool for predicting thermal performance of electronic circuit boards, improvements and refinements would be useful in several areas. The first recommendation would be for more experimental verification with particular emphasis towards developing better empirical heat transfer relationships for use in the present thermal model. The thermal model should also be expanded to include both the effects of natural convection and boundary conditions other than adiabatic. In particular the user should be able to specify a constant temperature for one or more of the physical circuit board boundaries. This would allow the modeling of installations that include metal card guides or cold plates.

The present model does not include the interaction that can occur between circuit boards mounted closely together. These effects could be included in the radiation sink temperatures "seen" by a board or included as effects on the local air temperature for the bottom and top of the circuit board.

Additional improvements could also be made in order to increase the number of circuit board designs that may be analyzed with THERMELEX. The limited set of components could be increased to include DIPs with different numbers

of pins and other flat pack case styles. Discrete components such as resistors, capacitors and switches are also able to transfer heat to the air stream and could also be included.

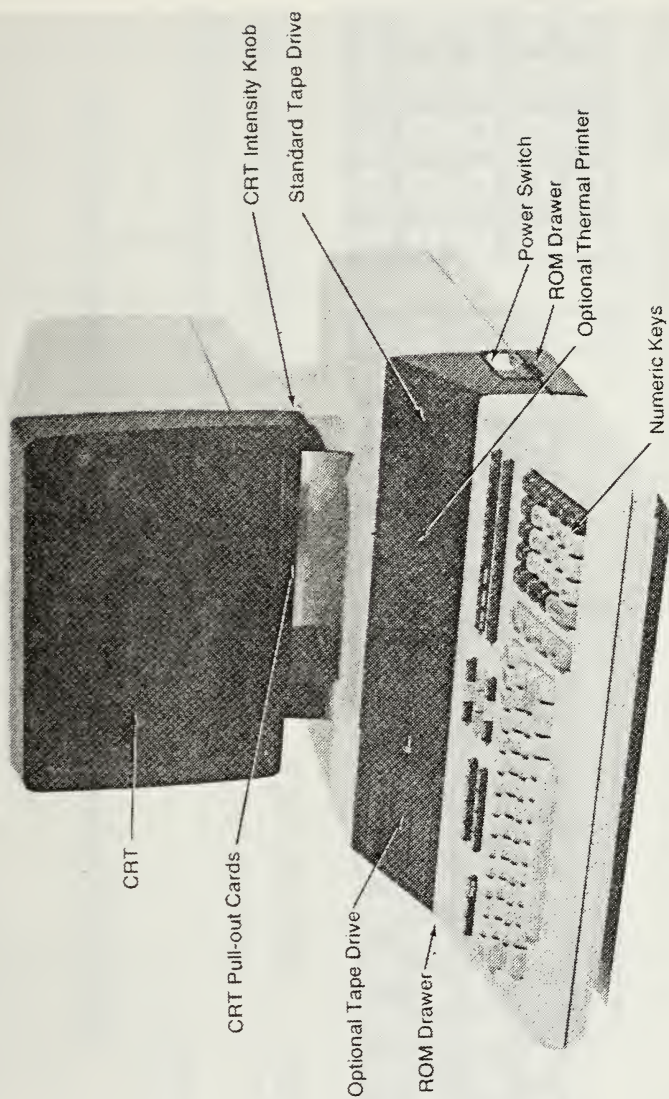
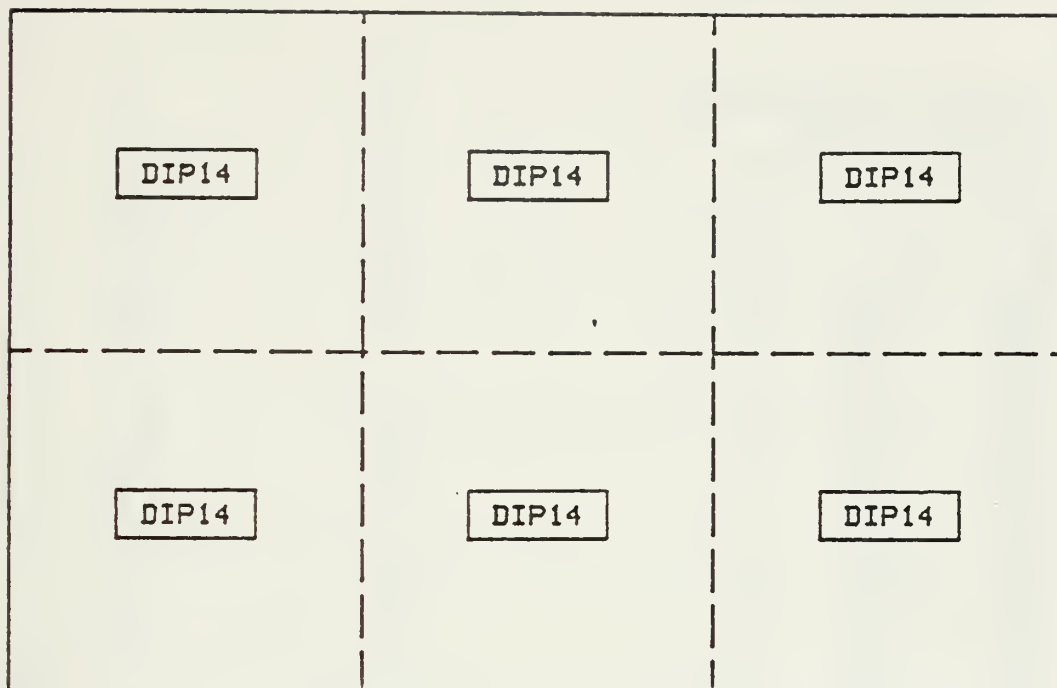


Figure 1. The Hewlett-Packard 9845 desktop computer



Nxr=3

Nyr=2

Nreg=6

Nxr=7

Nyr=6

Nreg=42

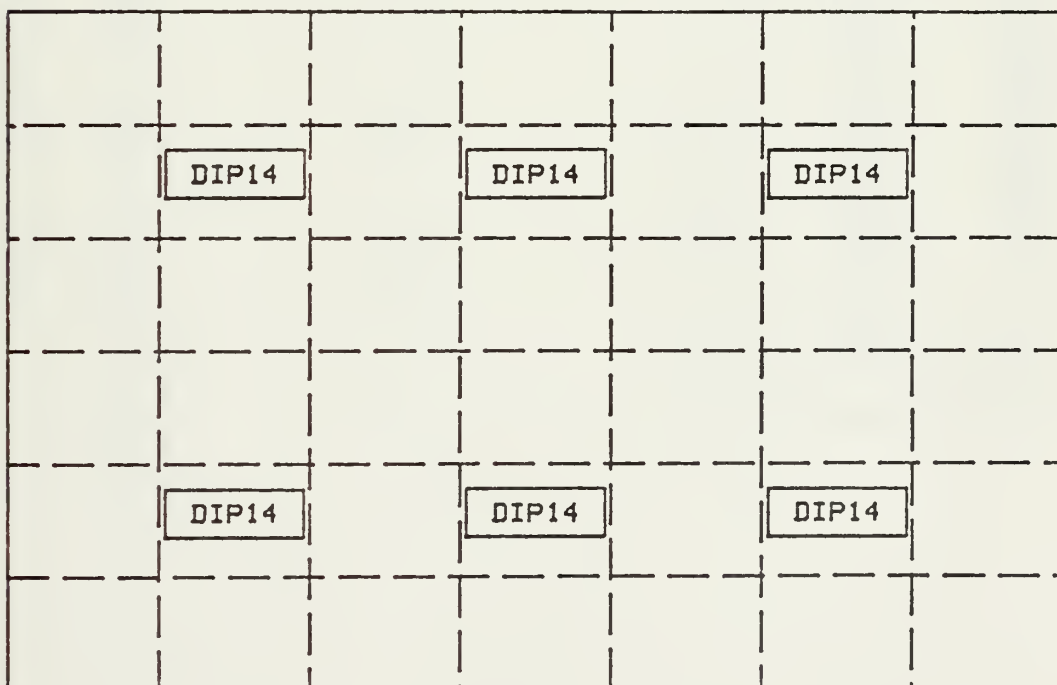


Figure 4. Alternate Region Definition for Single Circuit Board

TEAR OFF FOR COMPONENT DEFINITION KEY CODE OVERLAY

EMPTY	H0R12	VERT	H0R12	VERT	H0R12	VERT
(KO)	DIP14	DIP16	DIP16	DIP16	DIP24	DIP24
<div style="display: flex; justify-content: space-between;"> CHAR HERE PLACE ABOVE KEYS </div> <div style="display: flex; justify-content: space-between;"> ----- ----- </div> <div style="display: flex; justify-content: space-between;"> THEN PRESS CONT </div>						

		PLACE BELOW KEYS			
(K8)	VERT	FLAT	FLAT	FLAT	FLAT
H0R12	DIP40	16 PIN	24 PIN	40 PIN	64 PIN
DIP40					

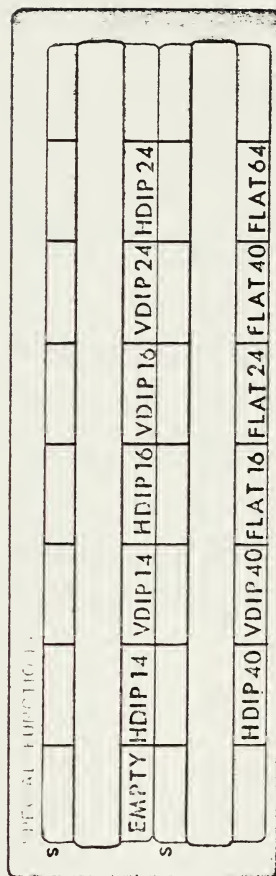


Figure 5: Component Definition Keycode Overlay

NELCO/NPGS TEST BOARD

---air flow---->

OF LEADS

1	0	2	0	3	0	4	0	5	0
0	DIP14	2	DIP14	2	DIP14	0	DIP14	2	DIP14
6	1	7	0	8	0	9	0	10	1
0	DIP14	2	DIP14	2	DIP14	2	DIP14	2	DIP14
11	2	12	0	13	0	14	0	15	2
0	DIP14	2	DIP14	2	DIP14	2	DIP14	2	DIP14
16	3	17	0	18	0	19	0	20	4
0	DIP14	2	DIP14	2	DIP14	2	DIP14	2	DIP14
21	4	22	0	23	0	24	0	25	5
0	DIP14	2	DIP14	2	DIP14	2	DIP14	2	DIP14
0	0	0	0	0	0	0	0	0	0

Figure 6. Graphics Dump of Circuit Board

REGION #	Tjunc (DegC)	Power (Watts)	Rcase-j(W/C)
1	0	.6	0
2	0	.6	0
3	0	.6	0
4	0	.6	0
5	0	.6	0
6	0	.6	0
7	0	.6	0
8	0	.6	0
9	0	.6	0
10	0	.6	0
11	0	.6	0
12	0	.6	0
13	0	.6	0
14	0	.6	0
15	0	.6	0
16	0	.6	0
17	0	.6	0
18	0	.6	0
19	0	.6	0
20	0	.6	0
21	0	.6	0
22	0	.6	0
23	0	.6	0
24	0	.6	0
25	0	.6	0

THE ABOVE DATA IS FOR HELCO/NPGS TEST BOARD

BOARD LENGTH (defined along air flow)= 142 mm HEIGHT = 114 mm

BOARD THICKNESS= 1.448 mm CONDUCTIVITY = .2942 Watts/M-K

THE MODEL ASSUMES LEADS AS CONDUCTION PATHS WITH AN AREA OF .000000026 mm²

THERMAL CONDUCTIVITY OF THE LEADS = 384 Watts/M-C

Figure 7. Data List of Circuit Board

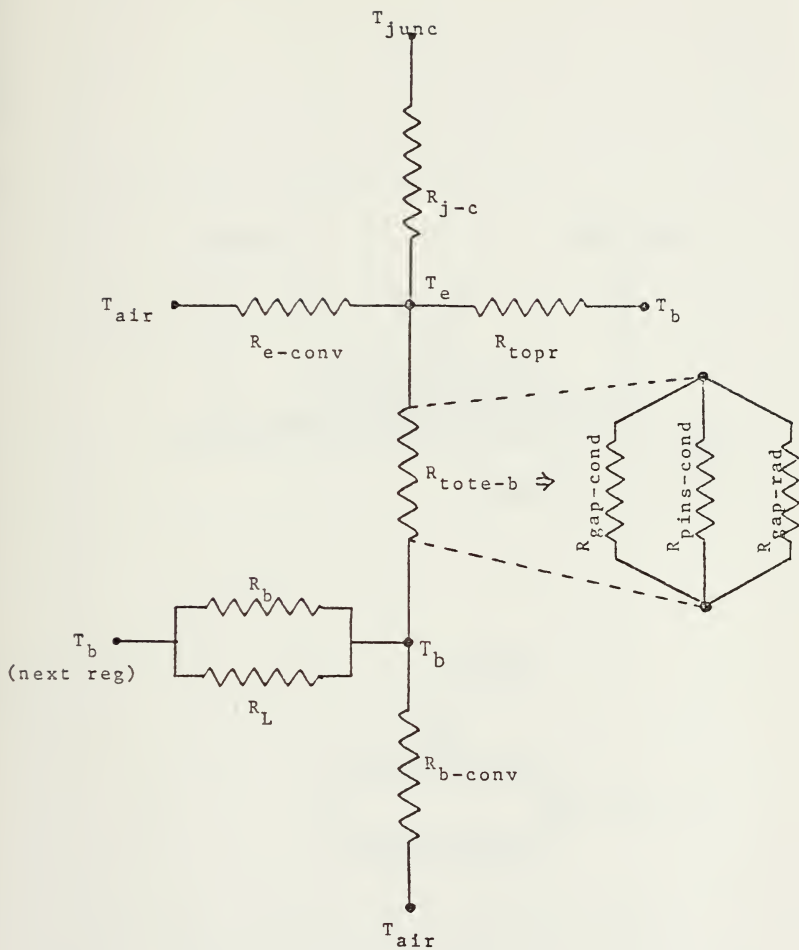


Figure 8 Thermal Network of Components and Circuit board

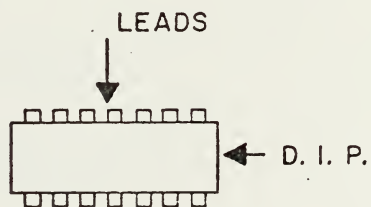
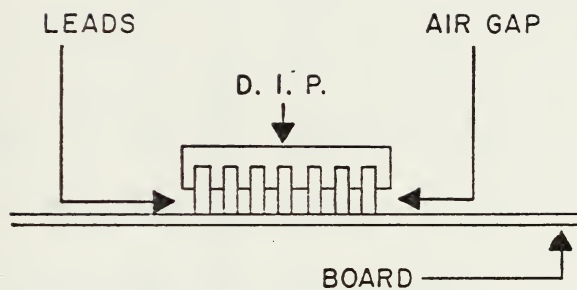
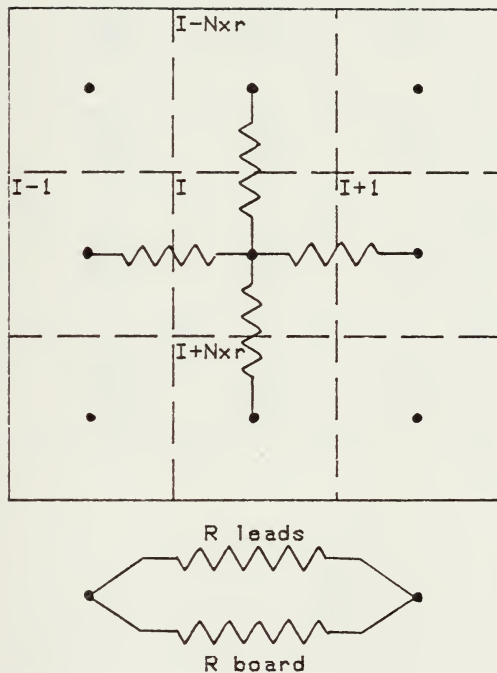


Figure 9: DIP Mounting on Circuit Board



CONDUCTIVE THERMAL RESISTANCE BETWEEN REGIONS

Figure 10. Thermal Network of the Bare Circuit Board

OUTPUT DATA FOR NELC/NPGS TEST BOARD

---110 flow---

1 DIP 14 38.7 C .600 W 23.7 C	2 DIP 14 41.1 C .600 W 26.1 C	3 DIP 14 42.7 C .600 W 27.7 C	4 DIP 14 ** 44.1 C .600 W 29.1 C	5 DIP 14 ** 45.3 C .600 W 30.3 C
6 DIP 14 38.7 C .600 W 23.7 C	7 DIP 14 41.1 C .600 W 26.1 C	8 DIP 14 42.7 C .600 W 27.7 C	9 DIP 14 ** 44.1 C .600 W 29.1 C	10 DIP 14 ** 45.3 C .600 W 30.3 C
11 DIP 14 38.7 C .600 W 23.7 C	12 DIP 14 41.1 C .600 W 26.1 C	13 DIP 14 42.7 C .600 W 27.7 C	14 DIP 14 ** 44.1 C .600 W 29.1 C	15 DIP 14 ** 45.3 C .600 W 30.3 C
16 DIP 14 38.7 C .600 W 23.7 C	17 DIP 14 41.1 C .600 W 26.1 C	18 DIP 14 42.7 C .600 W 27.7 C	19 DIP 14 ** 44.1 C .600 W 29.1 C	20 DIP 14 ** 45.3 C .600 W 30.3 C
21 DIP 14 38.7 C .600 W 23.7 C	22 DIP 14 41.1 C .600 W 26.1 C	23 DIP 14 42.7 C .600 W 27.7 C	24 DIP 14 ** 44.1 C .600 W 29.1 C	25 DIP 14 ** 45.3 C .600 W 30.3 C

TYPE Tjunc POW Tcase	or	EMPTY Tboard
-------------------------------	----	-----------------

FLOW RATE VELOCITY Tin Tout
 COOLING AIR .0078M³/Sec 4.5596M/Sec 20.0deg C 21.8deg C

LARGEST CHANGE IN TEMP BETWEEN ITERATIONS # 1 AND # 2 .0025

CIRCUIT BOARD DESCRIPTION IS STORED UNDER TEST#

Figure 11. Final OUTPUT DATA from THERML.(Temperature Solution)

DATA FOR HELD/NPGS TEST BOARD # 1 ITERATION

REG #	Tcase (DegC)	Tjunc (DegC)	Treg (DegC)	Pow (W)	Rj-c(W/C)
1.00	23.66	38.66	23.16	.60	25.00
2.00	26.06	41.06	25.55	.60	25.00
3.00	27.74	42.74	27.23	.60	25.00
4.00	29.12	44.12	28.62	.60	25.00
5.00	30.33	45.33	29.83	.60	25.00
6.00	23.66	38.66	23.16	.60	25.00
7.00	26.06	41.06	25.55	.60	25.00
8.00	27.74	42.74	27.23	.60	25.00
9.00	29.12	44.12	28.62	.60	25.00
10.00	30.33	45.33	29.83	.60	25.00
11.00	23.66	38.66	23.16	.60	25.00
12.00	26.06	41.06	25.55	.60	25.00
13.00	27.74	42.74	27.23	.60	25.00
14.00	29.12	44.12	28.62	.60	25.00
15.00	30.33	45.33	29.83	.60	25.00
16.00	23.66	38.66	23.16	.60	25.00
17.00	26.06	41.06	25.55	.60	25.00
18.00	27.74	42.74	27.23	.60	25.00
19.00	29.12	44.12	28.62	.60	25.00
20.00	30.33	45.33	29.83	.60	25.00
21.00	23.66	38.66	23.16	.60	25.00
22.00	26.06	41.06	25.55	.60	25.00
23.00	27.74	42.74	27.23	.60	25.00
24.00	29.12	44.12	28.62	.60	25.00
25.00	30.33	45.33	29.83	.60	25.00

BOARD THICKNESS= 1.45 mm AND CONDUCTIVITY = .29 Watts/M-K

COOLING AIR FLOW OF .0070 M³ per SEC VEL= 4.5596 M/Sec (59.2743 FT/S)

INLET AIR TEMP= 20.0000 deg C OUTLET AIR TEMP= 21.8091 deg C

LARGEST DIFFERENCE BETWEEN ITERATIONS = 3.3396 *****

Figure 12. Intermediate OUTPUT Data from THERML

OUTPUT DATA FOR NELC/NIPQS TEST BOARD .. POWER SOLUTION

---air flow-->

1 DIP 14 80.0 C 2.715 W 80.0 C	2 DIP 14 80.0 C 1.160 W 80.0 C	3 DIP 14 80.0 C .722 W 80.0 C	4 DIP 14 80.0 C .503 W 80.0 C	5 DIP 14 80.0 C ** .371 W 80.0 C
6 DIP 14 80.0 C 2.715 W 80.0 C	7 DIP 14 80.0 C 1.160 W 80.0 C	8 DIP 14 80.0 C .722 W 80.0 C	9 DIP 14 80.0 C .503 W 80.0 C	10 DIP 14 80.0 C ** .371 W 80.0 C
11 DIP 14 80.0 C 2.715 W 80.0 C	12 DIP 14 80.0 C 1.160 W 80.0 C	13 DIP 14 80.0 C .722 W 80.0 C	14 DIP 14 80.0 C .503 W 80.0 C	15 DIP 14 80.0 C ** .371 W 80.0 C
16 DIP 14 80.0 C 2.715 W 80.0 C	17 DIP 14 80.0 C 1.160 W 80.0 C	18 DIP 14 80.0 C .722 W 80.0 C	19 DIP 14 80.0 C .503 W 80.0 C	20 DIP 14 80.0 C ** .371 W 80.0 C
21 DIP 14 80.0 C 2.715 W 80.0 C	22 DIP 14 80.0 C 1.160 W 80.0 C	23 DIP 14 80.0 C .721 W 80.0 C	24 DIP 14 80.0 C .502 W 80.0 C	25 DIP 14 80.0 C ** .371 W 80.0 C

TYPE	or	EMPTY
Tjunc		Tboard
POW		.
Tcase		

COOLING AIR FLOW RATE VELOCITY Tin Tout
 .0005M³/Sec .3257M/Sec 20.0deg C 66.1deg C

LARGEST CHANGE IN POWER BETWEEN ITERATIONS # 8 AND # 9 .0039

CIRCUIT BOARD DESCRIPTION IS STORED UNDER POWST

Figure 13: Final Output Data From Therml (power solution)

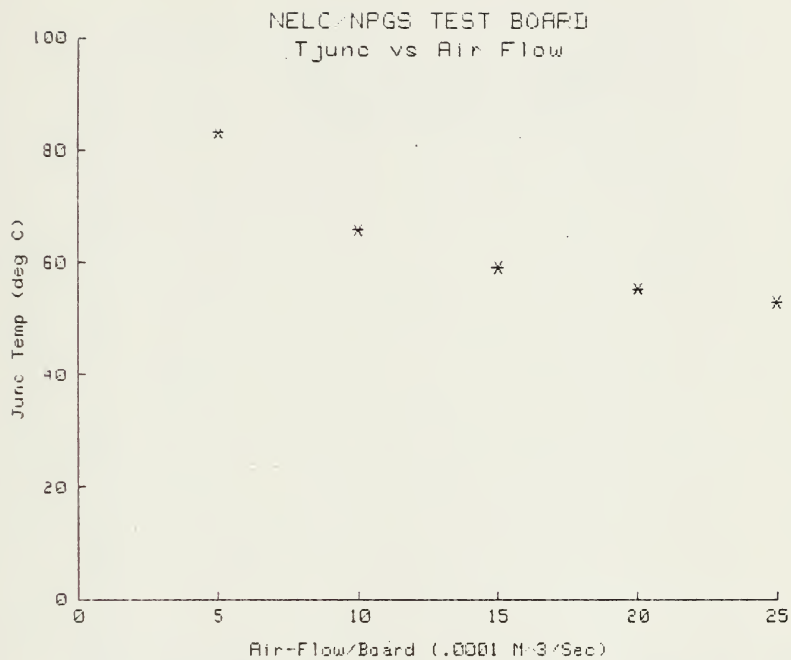


Figure 14. Sensitivity Plot: TJUNC vs Air Flow

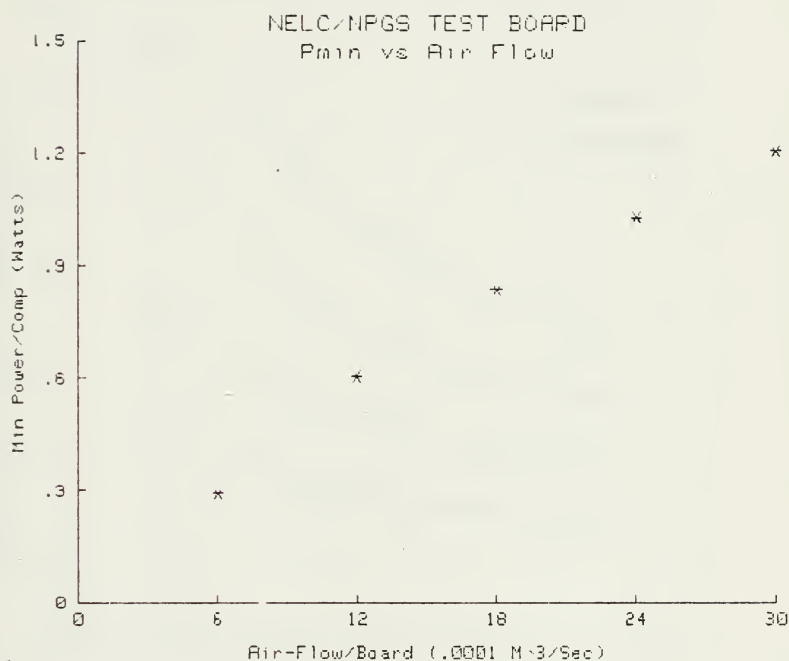


Figure 15. Sensitivity Plot: Power vs Air Flow

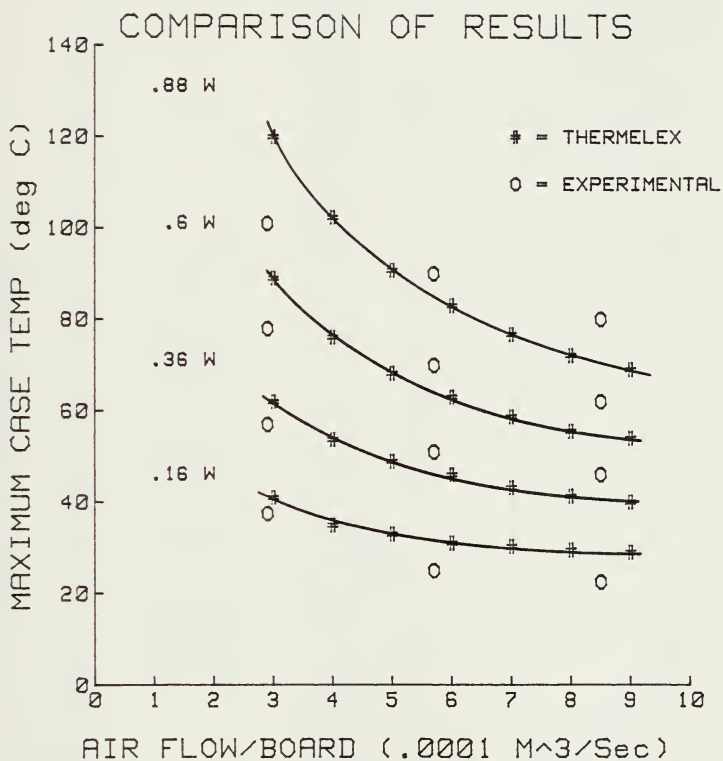


Figure 16. Comparison of THERMELEX Predicted Case Temperatures with Experimental Results from Ref. 14

APPENDIX A

** INSTRUCTIONS FOR USE OF THERMELEX **

The THERMELEX system is designed to perform thermal analysis of air cooled electronic circuit boards. The system consists of three major programs:

1. AUTOSI Driver and system setup.
2. BOARDS Input and recording of data.
3. THERML Analysis and output of results.

The AUTOSI program establishes special key definitions and acts as the driver for the other programs within the THERMELEX system. The key definitions are valid throughout the system except when entering the specific component type codes during execution of BOARDS.

This driver program is entered by placing the tape in the primary tape transport (:T15) at the right side above the special keys. You then:

TYPE: LOAD "AUTOSI:T15",1 Then Press EXECUTE

If the 9845A is off, the driver may be loaded by inserting the tape in :T15, latching the AUTO SI Key in the down position, and turning the power on. In either case the first question will be concerning the location of the THERMELEX system. The program will convert the default mass storage device to what ever device contains the system. It is important to not change this while using THERMELEX. These instructions may be provided on paper or CRT and a paper keycode overlay may be provided as a guide to the key definitions that is loaded by AUTOSI. A plastic overlay is available from Hewlett-Packard (part # 7120-8124) which may be filled in using the paper overlay as a guide. The other programs are entered from the option selection list (Menu) in AUTOSI. Normally BOARDS is next loaded to allow the input of circuit board descriptive data from the keyboard. The instructions that follow apply to this option.

The user should have either the circuit board or a facsimile available while he is using the BOARDS program. Orient the board such that the cooling air flow is from the left to the right. Measure the length (defined in the air flow direction), width and thickness of the circuit board in millimeters (mm). It is necessary to divide the board into evenly spaced imaginary regions in both horizontal and vertical directions. The centers of each of these regions will form the nodes of a finite difference grid to be used in the thermal analysis of the electronic circuit board. The imaginary lines that are created divide the circuit board into regions that will either be empty or will contain one component. An exception to this rule is the case of 40 pin DIP's which occupy two regions due to their large size. An attempt to approximate the real circuit board with a model requires some flexibility and imagination at this point.

The thermal model used for the analysis will assume that each component is centered in the region. The following components can be included:

<u>DIPS (horizontal or vertical)</u>	<u>CHIP CARRIERS</u>
14,16,24,40 pins	16,24,40,64 pins

The limitations imposed by restricting the components to the list above will prevent some circuit boards from being precisely modeled using THERMELEX but are necessary to provide for the simple input of the descriptive data.

When BOARDS is loaded using option #1 in AUTOST a control parameter is assigned which causes the program to begin at the section which asks for the geometric parameters of the bare circuit board. You will be asked to enter the length of the board in millimeters. Enter the length using either the number pad at the far right of the keyboard or the numbers above the letter keys followed by the CONT key. The next question will appear at the bottom of the screen while the length that was just entered will be printed immediately below the instructions. Answer each question remembering to use the CONT key and check the values on the screen. If a mistake is made press R0 and the program will ask the question again. After the length, height, thickness, conductivity, number of regions in the 'X' direction and the number of regions in the 'Y' direction have been entered, the program will ask for a short (less than 50 characters) descriptive title. This title will become part of the data set for the circuit board and will be used to identify the output. Two examples are:

TEST BOARD FOR PROJECT UNIFYFRATS or DESCRIPTIVE TITLE #1234.98 .

The screen will now shift from the alpha mode to the graphics mode and draw an empty board with the imaginary regions marked off with dotted lines. This picture will remain on the screen for only 3 sec after it is drawn but it may be returned to the screen using k2 to allow further time for checking. K1 will return the screen to the alpha mode for the next section.

The special function keys will now be used to input the contents of each of the regions defined on the blank board. This is the last chance to use the Back-up option (k6) if the board is not correct. A new Key code overlay will be provided if necessary and must replace the general purpose overlay on the keyboard. The keys defined in this section act as priority interrupts and will allow the screen to remain in the graphics mode as the components are defined. A flashing cross will move to each region in succession and wait for a valid key to be pressed. Every region must be defined even if empty. It is important to wait for the cursor to move to the next empty region before keys are pressed. The back-up option will NOT work while defining components but there will be an opportunity to make corrections in the next section. When all regions have been defined, the screen will return to the alpha mode to ask if there are any corrections. At this point k2 will return the graphics to the screen and k1 will return the alpha mode to the screen.

To make corrections, the numbers of ALL incorrect regions are entered and the components erased. When there are no more to be removed, pressing CONT with no entry will allow all empty regions to be redefined. A flashing cross will visit each empty region followed by further correction opportunity as needed. When the board is correct, the general purpose key definitions are returned and the normal key code overlay should be replaced.

DIP components generally are produced in two different case styles, ceramic or plastic. These are different sizes and this affects the thermal analysis performed in ITCRHL. The next section provides several methods to specify the case styles for the DIP's. These are: 1) all plastic...2) all ceramic... 3) majority ceramic (user specify which are plastic)...4) majority ceramic (user specify which are ceramic)...5) user specify case style for each DIP component. In general, option 3 or 4 require the user to input the number of regions that are either plastic or ceramic and are useful for specifying the style when only a few are different. When there is a nearly equal mix, option 5 requires a 1 for plastic style and a 0 for ceramic style. After all DIP's are specified, a list of region numbers is displayed on the screen (in alpha mode) with the plastic cases in inverse video (numbers black on light background) and ceramic cases in normal video. Correct as needed and again no corrections is indicated by pressing CONT Key with no entry.

The next section concerns the thermally conductive paths that are added to the circuit board. Both the electrical conductors and any thermal conduction paths or rails will transfer heat between regions. When any conduction rails are present, the effects of the electrical leads will be negligible and ignored. To aid in the modelling of the conduction rails it is necessary to introduce the concept of a Conduction Path Unit (CPU). Each of the rails is modelled as containing an integer number CPU's. The width of a CPU is defined to be .1 mm while the user must define the thickness (mm) and thermal conductivity (Watts/M-C) of the material that forms the conduction rails. The thermal conductivities of several aluminum alloys and copper are presented to aid the user. If there are no conduction rails present, the electrical lead description is entered in the much the same way; thickness (mm), average width (mm) and the conductivity (Watts/M-C). This will default to 384 Watts/M-C, the value for copper. This is the most common material for traces on circuit boards.

In the next section the numbers of leads or CPU's that cross the interior boundaries between regions are entered. The display will alternate between the graphics and the alpha mode with the flashing cross or cursor moving to the appropriate location on the board to be defined. The graphics will remain on the screen for two seconds and then return to the alpha mode for an input line. It will ask for the input of the number of leads or CPU's between two specific regions; ie if the conduction rail is 6.7 mm wide, there are 67 CPU's in that path. Special function key 3 (F3) may be used to dump the graphics to the printer for a hard copy of the graphics picture. It is important to account for the leads on both sides of the circuit board when entering this number. As before follow all entries with the CONT key. Because of the program flow in this section, the Back_up option (K8) will not function. Do not attempt to make corrections or return to a previous section until after all entries have been made. All connections will be made in the next section.

In the thermal model used by the THERMEX system, all heat is transferred to the cooling air stream. None of the heat is transferred out the edges of the circuit board. For this reason, the sides of the regions at the edges will be labeled with 0 to indicate that no leads or CPU's cross this boundary. When this heat loss from the board edges and connection is neglected, the results will be conservative. These assumptions may be unacceptable for circuit boards used in installations where a significant fraction of the total heat dissipated is conducted away from the board through card guides or connectors.

When all regions have been specified, the screen will return to the alpha mode and ask if any corrections are needed. Use the special functions keys as required to either return to graphics/alpha or produce a hard copy. Enter the numbers of the connecting regions that have incorrect values for the numbers of leads or CPU's. As before, CONT with no entry signals the lack of further connections. The physical description of the circuit board is now complete. All that remains is to specify either the component power levels (Watts) or the junction temperatures for each component.

When the maximum junction temperatures for the components are specified, the maximum steady state power level that will result in that temperature is calculated for each component. When the steady state power of each component is specified, the steady state junction temperatures are calculated. In either situation it is also necessary to specify the case to junction thermal resistance R_{j-c} (Deg C/Watt). The thermal model uses the component surface temperatures for heat transfer calculations and R_{j-c} provides the limit between the component power, junction temperature and the surface temperature. If R_{j-c} is specified as zero (0) then the case surface temperature will be equal to the junction temperature.

After all component power levels or junction temperatures have been set, the complete list is displayed in the alpha mode to allow checking and changes. Corrections are inserted by entering the incorrect region number then entering the correct values in response to the question asked. If desired a hard copy of all data for the circuit board will be provided from the printer.

The next section allows recording of the circuit board descriptive data on to a mass storage media. This should be done. The recorded data file may be accessed at some later time either in EORFDS for editing and changes or directly in THERM to perform the thermal analysis. EORFDS will create the necessary data file to record the description but if a data file of sufficient size exists, it may be used. All old data in that file will be permanently lost. Information concerning the minimum data file size is presented by the program to help in this decision.

Built in error traps throughout the entire THERMELEX system will save the user from loss of previous inputs in case of errors. Information about the error is presented and using the error message guide on the plastic slide outs below the screen, the user may be able to make corrections. When ready, as signaled by CONT key, program flow returns to a previous point and operation resumes. The data recording section where file names are entered is particularly prone to spelling errors or entry of incorrect mass storage unit specifiers. Be careful but remember the system will attempt to catch those inevitable errors and act on them before they become fatal.

The end of a cycle through BOARDS is now complete. As the page heading that will appear states, WHAT NOW? More work with BOARDS is possible. The user may either input another circuit board description from the keyboard and record that to mass storage; or, he may retrieve a different circuit board descriptive data set from mass storage for checking and corrections. Another option is to perform the thermal analysis of the circuit board using the third program in the THERMELEX system, THERML.

Before an explanation of the program flow in THERML, some explanation of the use of BOARDS to edit previously recorded data files is in order. This option may be accessed through the use of QUIT001 as explained on the first page of these instructions or the BOARDS program may be directly entered into the computer with the command: LOAD "BOARDS:T15,1" then Press EXECUTE

Of course the appropriate mass storage specifier should be used both here and when entering the file name for any previously recorded data file. See the Operating and Programming Manual for the 9845 if the above is not clear.

Following the input of the file name that contains the descriptive data, the data file will be read and all the variables that are normally set from the keyboard will be defined. The circuit board will be drawn on the screen in graphics mode and changes to the specific components that occupy the regions may be made. However, it is not possible to change the number of regions in any way. This major revision of the board must be done as a new board input. Correction to case styles is next and then the numbers of leads or CPU's between regions will be labelled on to the graphics picture of the circuit board. Changes will be allowed to the numbers but not the physical sizes of the leads or CPU's; this also requires a new board input. A list of power levels, junction temperature and case to junction thermal resistances is presented for checking and corrections as required. This edited descriptive data set may then be recorded either back to the same data file or to a new file.

There are two demonstration data files included in the THERMELEX system. DEMO-I contains a typical circuit board description needed to determine the steady state junction temperature (ie component power levels are specified). DEMO-P contains a different circuit board for which maximum powers levels are determined in the thermal analysis. The use of either of these can be helpful to familiarize the user with both BOARD and the last program in the THERPELEX system, THERML.

THERML creates the mathematical model, performs the analysis of the circuit board and produces the output. The variables used in the thermal model are set using either a data file from mass storage or they are passed in a common block when THERML is loaded from BOARD. There are no connection opportunities for the circuit board descriptive variables in this program.

Assuming that THERML has been loaded from the What How option list in BOARD, the first input is the inlet temperature (deg C) of the cooling air. After this is entered and printed on the screen, the volumetric air flow rate (M³/sec) is requested. Since the same set of general purpose special function keys are valid in this program, the keycode overlay should remain and k0 (Back-up) may be used to return to a previous question when input errors are made. The next input is the spacing between the circuit boards for rack mounts. This spacing and the board height determines the size of the imaginary air duct containing the circuit board. When combined with the amount of air flow for each circuit board the air velocity and heat transfer correlations are determined. Since all the power dissipated on the circuit board must be removed by the air flow, it is important for these values to be as precise as possible. After the thermal analysis is complete, there will be opportunities to alter these important air flow parameters and examine the effects on the output.

Before the analysis begins, the convergence criteria must be set. The analysis consists of assuming a solution then defining a set of simultaneous equations (one for each region) which are solved for either the power or the junction temperatures. The results are compared to the previous results (the assumed values for the first iteration) and if the largest difference between these values is less than a maximum set by the user, the results are presented in graphics. If the convergence criteria is not met, the results are printed to the screen in alpha mode and another iteration is entered. The closer to zero one sets the convergence criteria, the longer the process takes. Default values for the convergence criteria are .5 Deg C or 1% change in power. These typically require 2 to 6 iterations before they are met. Each iteration takes 5 to 100 sec to perform depending on the number of regions. As the solution proceeds the user may view the intermediate results to watch the progress.

The final results are written onto a picture of the circuit board with each region containing component type, junction temperature, power level and case temperature. Empty regions contain only the temperature of the circuit board. Those junction temperatures within 5% of the maximum and those power levels within 5% of the minimum are starred (**) for easy reference as trouble spots. This graphics output is automatically dumped to the printer to insure that a hard copy of the results exist.

This completes a cycle through THERML and again the question is What Now? BOARDS may be returned to core, to make changes to the circuit board or to enter a new circuit board. Another analysis of the same circuit board may be done with a new set of air flow parameters or, a new circuit board descriptive data set may be read in from mass storage with THERML.

An additional option is sensitivity analysis. Plots of the maximum Tjunc vs. Air Flow Rate or the minimum Power vs. Air Flow Rate may be produced. A maximum air flow rate is specified and five separate analyses are performed and the results plotted and dumped to the printer. The maximum air flow rate specified should be an integer multiple of five to make for better looking axes. It is also possible to produce hard copies of the printed results for each of the air flow rates. Upon completion of this sensitivity analysis, program flow returns to the option list previously discussed.

Termination should be done under program control using the final option. This will insure that the standard key definitions are returned and that the proper graphics parameters are set for the next user of the computer.

GOOD LUCK

APPENDIX B

```

10 | AUTOST      .... DRIVER PROGRAM FOR ....
20 |
30 | ***** THERMELEX *****
40 | *
50 | *      A SYSTEM OF PROGRAMS FOR THE HP 9845
60 | *
70 | *      TO PERFORM THERMAL ANALYSIS OF ELECTRONIC CIRCUIT BOARDS
80 | *
90 | *****
100 | *
110 | *
120 | *      PREPARED AT THE NAVAL POSTGRADUATE SCHOOL MONTEREY
130 | *
140 | *      R. A. FOLTZ LCDR USN
150 | *
160 | *
170 | *      |||||  AUTOST  |||||
180 | *
190 | *
200 | *****
200 | PRINTER IS 0
210 | PRINT CHR$(27+27)";134T"
220 | DIM S$(60)
230 | COM Map
240 | PRINTER IS 16
250 | GOSUB Setsto
260 | GOSUB Init
270 | IF Ans$="BACK UP" THEN GOTO 240
280 | GOTO Start
290 | Start: GOSUB Error
300 | Start: S$="NOTE TO USER ABOUT SPECIAL FUNCTION KEYS"
310 | ON ERROR GOTO Start
320 | GOSUB Pagehead
330 | PRINT "      The following user-keys will be in effect unless otherwise note
340 | PRINT "In general these key definitions are valid only when the program
350 | PRINT "for an input (ie Run light in lower right corner is off). The Back
360 | PRINT "(k0) returns the program to a previous question or control point."
370 | PRINT
380 | PRINT "This should be used when the user decides he has made some error on
390 | PRINT "can be corrected by re-entering the data."
400 | PRINT
410 | PRINT "If you do not have a plastic key code overlay filled in (hp # 7120-
420 | PRINT "a paper one will be provided."
430 | PRINT LIN(1)
440 | PRINT "      KEY 'k0' will back up to the previous question."
450 | PRINT "      KEY 'k1' will display printed output.      (EXIT GRAPHICS)"
460 | PRINT "      KEY 'k2' will display plotted output.      (GRAPHICS)"
470 | PRINT "      KEY 'k3' will print copy of plotted output.  (DUMP GRAPHICS)"
480 | PRINT "      KEY 'k4' will disable internal printer.      (PRINTER IS 16)"
490 | DISP "Press CONT WHEN READY FOR MORE EXPLANATIONS"
500 | PAUSE
510 | PRINT "      KEY 'k5' will enable internal printer.      (PRINTER IS 0)"
520 | PRINT "      KEY 'k6' will rewind left hand tape.      (REWIND :T14 )"
530 | PRINT "      KEY 'k7' will rewind right hand tape.      (REWIND :T15 )"

```


AUTOST .. DRIVER FOR THERMELEX

```

540 PRINT "      KEY 'K14' will answer Yes."
550 PRINT "      KEY 'K15' will answer No."
560 PRINT LINK(2)
570 PRINT "In general when answering questions or selecting an option pressing
CONT "
580 PRINT "with no other entry will assign either the default or the first opt
ion in"
590 PRINT "parentheses (the first option in the list) as the desired option."
600 PRINT LINK(1)
610 PRINTER IS 16
620 GOSUB Overlay
630 IF Ans#="BACK UP" THEN 260
640 DISP "LOADING KEY DEFFINITIONS"
650 IF Map=0 THEN LOAD KEY "BDSKEY"
660 WAIT 1000
670 GOTO 690
680 Optionse: GOSUB Error
690 Options: S#="MAIN PROGRAM OPTIONS"
700 ON ERROR GOTO Optionse
710 GOSUB Pagehead
720 PRINT "      The THERMELEX program package consists of three major sections,
one of"
730 PRINT "which is in core now providing these instructions. The other two a
re called"
740 PRINT "BOARDS and THERML. Both have the capability to read circuit bo
and data"
750 PRINT "from a Mass Storage Device (eg Tape or Disk) but only BOARDS can:
"
760 PRINT "(a) Input circuit board description from keyboard...";
770 PRINT "(b) Allow graphical checking of descriptions...";
780 PRINT "(c) Make connections to descriptions as required...";
790 PRINT "(d) Record descriptions to mass storage..."
800 PRINT LINK(1), "THERML performs the thermal analysis and output of results
."
810 PRINT LINK(1), "YOUR OPTIONS ARE:"
820 PRINT "      1. LOAD BOARDS TO INPUT DESCRIPTION FROM KEYBOARD."
830 PRINT LINK(1), SPAC(20), "2. LOAD BOARDS TO READ DESCRIPTION OFF MASS STORAG
E"
840 PRINT LINK(1), SPAC(20), "3. LOAD THERML TO READ DESCRIPTIONS OFF MASS STORA
GE"!
850 PRINT LINK(1), SPAC(20), "4. COPY ALL PROGRAMS "
860 Ans#="1"
870 INPUT "YOUR CHOICE ? (1,2,3,4)", Ans#
880 IF Ans#="BACK UP" THEN Start
890 Ans=INT(VAL Ans#)
900 IF (Ans>0) AND (Ans<5) THEN 930
910 GOSUB Errin
920 GOTO Options
930 IF Ans=1 THEN Map=2
940 IF Ans=2 THEN Map=3
950 ON Ans GOSUB Gen, Gen, Therml, Copy
960 GOTO Options
970 Gen: DISP "LOADING GENERAL CIRCUIT BOARD PROGRAM "
980 LOAD "BOARDS", 1
990 STOP
1000 Therml: DISP "WORKING LOADING THERML "
1010 LOAD "THERML", 10
1020 STOP

```


AUTOST .. DRIVER FOR THERMELEX

```

1030 Copy:=GOSUB Errin
1040 Copy: ! THIS SECTION FOR PROGRAM REPRODUCTION ONTO ANOTHER MASS STORAGE
1050 ON ERROR GOTO Copye
1060 S$="COPYING THERMELEX PROGRAMS"
1070 GOSUB Pagehead
1080 PRINT "    This section allows easy reproduction of THERMELEX from one mass
storage"
1090 PRINT "device to another.  The mass storage medium (tape or disk) must be i
nitialized."
1100 PRINT "If the medium intended as the destination is new or you wish to eras
ae all"
1110 PRINT "files then the use of option 2 will perform this task.  Since the TH
ERMELEX"
1120 PRINT "system requires only approximately 500 records, it is possible to use
a medium"
1130 PRINT "that already contains files to be retained; however, this may not al
low"
1140 PRINT "sufficient space for the data files containing the circuit board des
criptions."
1150 PRINT "Option 1 will record in the available spaces if possible but it is r
ecommended"
1160 PRINT "that an entire mass storage media be devoted to THERMELEX."
1170 PRINT LIN(1),"YOUR OPTIONS ARE:";
1180 PRINT "    1. COPY ALL PROGRAMS WITHOUT INITIALIZATION."
1190 PRINT LIN(1),SPAC(20),"2. COPY ALL PROGRAMS AFTER INITIALIZATION."
1200 Ans#="1"
1210 INPUT "YOUR CHOICE FROM ABOVE (1 or 2)",Ans#
1220 IF Ans#="BACK_UP" THEN Options
1230 Ans#INT(VAL(Ans#))
1240 IF (Ans#1) OR (Ans#2) THEN 1270
1250 GOSUB Errin
1260 GOTO Copy
1270 Ans#:=Msus1#
1280 EDIT "WHAT MASS STORAGE DEVICE CONTAINS THE THERMELEX SYSTEM (:T15,:T14,:F8
,ETC)",Ans#
1290 IF Ans#="BACK_UP" THEN Copy
1300 IF Ans#(1,1)="/" THEN Ans#=":"&Ans#
1310 Msus1#:=Ans#
1320 Ans#=":T14"
1330 EDIT "WHAT MASS STORAGE DEVICE CONTAINS THE DESTINATION MEDIUM (:T14,:T15,:
F8,ETC)",Ans#
1340 IF Ans#="BACK_UP" THEN Copy
1350 IF Ans#(1,1)="/" THEN Ans#=":"&Ans#
1360 IF Ans#<Msus1# THEN 1450
1370 BEEP
1380 PRINT PAGE,LIN(10),SPAC(10),"HOW CAN I COPY FROM ";Msus1#;" TO ";Ans#
1390 PRINT SPAC(10),"TRY AGAIN"
1400 WAIT 2000
1410 BEEP
1420 WAIT 1500
1430 BEEP
1440 GOTO Copy
1450 Msus2#:=Ans#
1460 IF Ans#1 THEN Copy2
1470 BEEP
1480 PRINT PAGE,LIN(10),TAB(15),"
1490 PRINT
1500 PRINT TAB(15),"*****WARNING*****"

```


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```

1510 PRINT LINK2:
1520 PRINT TAB(15),"THIS PROGRAM WILL ERASE ALL FILES ON ";Mnu2$
1530 PRINT LINK2,TAB(15)," "
1540 PRINT LINK1,SPA(10),"USE F=0 TO BACK UP IF THIS IS NOT YOUR DESIRE"
1550 PRINT LINK1,SPA(20),"PRESS CONT IF THIS IS OK ....."
1560 WAIT 200
1570 BEEP
1580 INPUT Ans$
1590 IF Ans$="BACK UP" THEN Copy
1600 DISP "WORKING-INITIALIZING ";Mnu2$
1610 INITIALIZE Mnu2$
1620 IF Mnu2$(2,2)<>"T" THEN Copy2
1630 DISP "WORKING-SETTING UP ";Mnu2$
1640 CREATE "DUMMY"%Mnu2$,420
1650 CREATE "ENDSPA"%Mnu2$,1
1660 PURGE "DUMMY"%Mnu2$
1670 Copy2: IN THIS SECTION THE ACTUAL COPYING TAKES PLACE
1680 RESTORE 1750
1690 FOR I=1 TO 9
1700 READ Nam$
1710 COPY Nam%Mnu1$ TO Nam%Mnu2$
1720 DISP "COPYING ";Nam$;" FROM ";Mnu1$;" TO ";Mnu2$
1730 WAIT 1500
1740 NEXT I
1750 DATA BDSKEY,STDKEY,DEMO-T,DEMO-P,AUTOST,BOARDS,THERML,TNAMES
1760 RETURN
1770 !
1780 Setsto:GOSUB Error
1790 Setsto: THIS SECTION DETERMINES WHERE THE THERMELEX SYSTEM IS AND SETS
1800 ! MASS STORAGE TO THAT PLACE
1810 ON ERROR GOTO Setsto
1820 S$="LOCATION OF THE THERMELEX SYSTEM"
1830 GOSUB Pagehead
1840 PRINT " It is necessary that the mass storage media that contains the TH
ERMELEX"
1850 PRINT "system be located in the default mass storage device. Therefore, th
e default"
1860 PRINT "mass storage will be converted by the program. This should not be a
ltered"
1870 PRINT "during the use of THERMELEX. Data files located on other mass stora
ge devices"
1880 PRINT "may be accessed by appending the appropriate device code to the file
name."
1890 Ans$=":T15"
1900 EDIT "CHANGE OR ENTER BELOW THE LOCATION OF THERMELEX ?",Ans$
1910 Ans$=UPC$(Ans$)
1920 IF Ans$(1,1)<>":" THEN Ans$=":%Ans$
1930 IF (Ans$(2,2)="F") OR (Ans$(2,2)="T") OR (Ans$(2,2)="Y") OR (Ans$(2,2)="Z"
) THEN 1970
1940 BEEP
1950 GOSUB Errin
1960 GOTO Setsto
1970 Mnu1$=Ans$
1980 MASS STORAGE IS Mnu1$
1990 RETURN
2000 Overlay: THIS SECTION PREPARES AN OVERLAY FOR THE USER
2010 Ans$="Y"
2020 INPUT "DO YOU DESIRE A PAPER KEY-CODE OVERLAY (Y OR N)?",Ans$

```


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```

2030 IF (UPC$(Ans#)="N") OR (Ans#="BACK_UP") THEN RETURN
2040 PRINTER IS 0
2050 PRINT SPA(15), "TEAR OFF FOR GENERAL PURPOSE KEY CODE OVERLAY ", LIN(2)
2060 PRINT " |Back_up| EXIT | ENTER | DUMP | FRT IS | FRT IS | REWND | REWND |
      PLACE"
2070 PRINT " | (<k> ) | GRAPHIC | GRAPHIC | GRAPHIC | 16 | 0 | :T14 | :T15 |
      ABOVE KEYS"
2080 PRINT "TEAR HERE ----- THEN PRESS CONT ---"
2090 PRINT LIN(1)
2100 PAUSE
2110 PRINT " | (<k> ) | | | | | EDIT | YES | NO |
      PLACE"
2120 PRINT " | | | | | | LINE | | |
      BELOW KEYS"
2130 PRINT LIN(3)
2140 PRINTER IS 16
2150 RETURN
2160 ! END OF Overlay
2170 Pagehead:!! THIS SECTION PLACES DESIRED HEADING ON A BLANK CRT
2180 PRINT PAGE, TAB(34-LEN(S$)/2), "++ "; CHR$(132); S$; CHR$(128); " ++", LIN(2)
2190 RETURN
2200 Errin:!! THIS SECTION ALERTS THE USER TO AN ATTEMPT TO INPUT INVALID DATA
2210 BEEP
2220 PRINT PAGE
2230 DISP "INPUT OUT OF RANGE.....TRY AGAIN"
2240 WAIT 2500
2250 BEEP
2260 WAIT 1500
2270 BEEP
2280 RETURN
2290 ! END OF Errin
2290 Error:!!
2300 PRINTER IS 16
2310 PRINT LIN(10), TAB(20), "ERROR NUMBER "; EARN; "HAS OCCUPIED IN LINE ": EARN
2320 DISP "PRESS CONTINUE WHEN READY TO RESUME PROGRAM FLOW"
2330 PAUSE
2340 !
2350 Pagecnt:!! THIS SECTION SPEAKS THE INSTRUCTIONS INTO PAGES FOR THE CRT
2360 DISP "Press CONT when ready for more instructions"
2370 PRINT LIN(Blanks)
2380 PAUSE
2390 RETURN
2400 !
2410 Pageprt:!! THIS SECTION BREAKS THE PRINTED INSTRUCTIONS INTO PAGES
2420 PRINT LIN(Blanks)
2430 PRINT TAB(35), "Pg. "; Pagenum
2440 PRINT LIN(1), "
      "
2450 IF Pagenum>5 THEN RETURN
2460 PRINT LIN(4), TAB(37-LEN(S$)/2); CHR$(132); S$; CHR$(128); TAB(76); "Pg. "; Pagenum
+1, LIN(2)
2470 RETURN
2480 !
2490 Inst:GOSUB Error
2500 Inst:!! THIS SECTION PREPARES A SET OF WRITTEN INSTRUCTIONS FOR THE USER
2510 ON ERROR GOTO Inst
2520 S$="INSTRUCTIONS FOR USE OF THERMELEX"
2530 GOSUB Pagehead
2540 PRINT " A written set of instructions can be prepared for the user that
will help"

```


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```
2550 PRINT "one to become familiar with the THERMELEX system without actually using the "
2560 PRINT "the computer. These are intended to only supplement the set of directions"
2570 PRINT "given during the execution of the system of programs. These instructions will"
2580 PRINT "normally be presented on the screen but if you desire a hard copy of the"
2590 PRINT "instructions, ENTER YPRT rather than Y."
2600 Ans#="N"
2610 INPUT "DO YOU DESIRE PRINTED INSTRUCTIONS (N or Y OR YPRT)?",Ans#
2620 IF Ans#="BACK UP" THEN RETURN
2630 IF (UPC$(Ans$(1,1))="Y") OR (UPC$(Ans#)="N") THEN 2660
2640 GOSUB Errin
2650 GOTO Inst
2660 IF UPC$(Ans#)="N" THEN RETURN
2670 PRINTER IS 16
2680 PRINT PAGE
2690 IF UPC$(Ans$(1,2))="YP" THEN PRINTER IS 0
2700 P=16
2710 IF UPC$(Ans$(1,2))="YP" THEN P=0
2720 PRINT LINK(4),TAB(37-LEN(34)+2*P)+" :CHR$(132);8;CHR$(128);" +*,LIN(2)
2730 PRINT "The THERMELEX system is designed to perform thermal analysis of air cooled"
2740 PRINT "electronic circuit boards. The system consists of three major programs:"
2750 PRINT
2760 PRINT LINK(1),TAB(17),".1. AUTOST Driver and system setup."
2770 PRINT LINK(1),TAB(17),".2. BOARDS Input and recording of data."
2780 PRINT LINK(1),TAB(17),".3. THERML Analysis and output of results."
2790 PRINT LINK(1)
2800 PRINT "The AUTOST program establishes special key definitions and acts as the driver"
2810 PRINT "for the other programs within the THERMELEX system. The key definitions are "
2820 PRINT "valid throughout the system except when entering the specific component type"
2830 PRINT "codes during execution of BOARDS . "
2840 Blanks=0
2850 IF P=16 THEN GOSUB Pagecrt
2860 PRINT
2870 PRINT "This driver program is entered by placing the tape in the primary tape"
2880 PRINT "transport (T15) at the right side above the special keys. You then :",LIN(1)
2890 PRINT TAB(10),":TYPE: LOAD ";CHR$(34);":AUTOST:T15;CHR$(34);":1 Then Press EXECUTE "
2900 PRINT
2910 PRINT "If the 8845A is off, the driver may be loaded by inserting the tape in :T15,"
2920 PRINT "latching the AUTO ST Key in the down position, and turning the power on."
2930 PRINT "In either case the first question will be concerning the location of the "
2940 PRINT "THERMELEX system. The program will convert the default mass storage device"
2950 PRINT "to what ever device contains the system. It is important to not change this"
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2960 PRINT "while using THERMELEX. These instructions may be provided on paper
or CRT and"
2970 PRINT "a paper keycode overlay may be provided as a guide to the key defin
itions"
2980 PRINT "that is loaded by AUTOST. A plastic overlay is available from Hew
lett-Packard"
2990 PRINT "(part # 7120-6164) which may be filled in using the paper overlay as
a guide."
3000 PRINT "The other programs are entered from the option selection list(Menu)
in AUTOST."
3010 PRINT "Normally BOARDS is next loaded to allow the input of circuit board
descriptive"
3020 PRINT "data from the keyboard. The instructions that follow apply to this
option."
3030 PRINT
3040 Blanks=4
3050 IF P=16 THEN GOSUB Pagecrt
3060 PRINT " The user should have either the circuit board or a facsimile ava
ilable"
3070 PRINT "while he is using the BOARDS program. Orient the board such that
the cooling"
3080 PRINT "air flow is from the left to the right. Measure the length (defined
in the air"
3090 PRINT "flow direction), width and thickness of the circuit board in millime
ters (mm)."
```

3100 PRINT "It is necessary to divide the board into evenly spaced imaginary reg	ions in both"
3110 PRINT "horizontal and vertical directions. The centers of each of these re	gions will"
3120 PRINT "form the nodes of a finite difference grid to be used in the thermal	analysis"
3130 PRINT "of the electronic circuit board. The imaginary lines that are creat	ed divide"
3140 PRINT "the circuit board into regions that will either be empty or will con	tain one"
3150 PRINT "component. An exception to this rule is the case of 40 pin DIP's wh	ich occupy"
3160 PRINT "two regions due to their large size. An attempt to approximate the	real circuit"
3170 PRINT "board with a model requires some flexibility and imagination at this	point."
3180 PRINT	
3190 PRINT " The thermal model used for the analysis will assume that each co	mponent is"
3200 PRINT "centered in the region. The following components can be included:"	
3210 PRINT	
3220 PRINT "	<u>DIPS (horizontal or vertical)</u>
3230 PRINT "	<u>CHIP CARRIERS "</u>
3240 PRINT	14,16,24,40 pins 16,24,40,64 pins"
3250 Pagenum=1	
3260 Blanks=4	
3270 IF P=0 THEN GOSUB Pageprt	
3280 IF P=16 THEN GOSUB Pagecrt	
3290 PRINT "The limitations imposed by restricting the components to the list ab	ove will "
3300 PRINT "prevent some circuit boards from being precisely modeled using THERM	ELEX but "
3310 PRINT "are necessary to provide for the simple input of the descriptive dat	a."

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3320 PRINT
3330 PRINT " - When BOARDS is loaded using option #1 in AUTOST a control pa
parameter is"
3340 PRINT "assigned which causes the program to begin at the section which asks
for the"
3350 PRINT "geometric parameters of the bare circuit board. You will be asked t
o enter the"
3360 PRINT "length of the board in millimeters. Enter the length using either t
he number"
3370 PRINT "pad at the far right of the keyboard or the numbers above the letter
keys"
3380 PRINT "followed by the CONT Key. The next question will appear at the bo
ttom of the"
3390 PRINT "screen while the length that was just entered will be printed immedi
ately below"
3400 PRINT "the instructions. Answer each question remembering to use the CONT
Key and"
3410 PRINT "check the values on the screen. If a mistake is made press K0 and
the program"
3420 PRINT "will ask the question again. After the length, height, thickness, c
onductivity,"
3430 PRINT "number of regions in the 'X' direction and the number of regions in
the 'Y' "
3440 PRINT "direction have been entered, the program will ask for a short (less
than 50 "
3450 PRINT "characters) descriptive title. This title will become part of the d
ata set for"
3460 PRINT "the circuit board and will be used to identify the output. Two exam
ples are:"
3470 PRINT
3480 PRINT SPAC(5), "TEST BOARD FOR PROJECT UNIFYFRATS on DESCRIPTIVE TITLE
#1234.9A ."
3490 Blanks=0
3500 IF P=15 THEN GOSUB Pagecrt
3510 IF P=0 THEN PRINT
3520 PRINT " The screen will now shift from the alpha mode to the graphics mo
de and draw"
3530 PRINT "an empty board with the imaginary regions marked off with dotted lin
es. This"
3540 PRINT "picture will remain on the screen for only 3 sec after it is drawn b
ut it may"
3550 PRINT "be returned to the screen using k2 to allow further time for check
ing."
3560 PRINT "K1 will return the screen to the alpha mode for the next section."
3570 IF P=0 THEN PRINT
3580 PRINT " The special function keys will now be used to input the contents
of each of"
3590 PRINT "the regions defined on the blank board. This is the last chance to
use the "
3600 PRINT "Back-up option (k0) if the board is not correct. A new Key code ove
rlay will"
3610 PRINT "be provided if necessary and must replace the general purpose overla
y on the"
3620 PRINT "keyboard. The keys defined in this section act as priority interrup
ts and will"
3630 PRINT "allow the screen to remain in the graphics mode as the components ar
e defined."
3640 PRINT "A flashing cross will move to each region in succession and wait for
a valid"

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3650 PRINT "key to be pressed. Every region must be defined even if empty. It
is "
3660 PRINT "important to wait for the cursor to move to the next empty region be
fore keys"
3670 PRINT "are pressed. The back-up option will NOT work while defining comp
onents but"
3680 PRINT "there will be an opportunity to make corrections in the next section
."
3690 PRINT "When all regions have been defined, the screen will return to the al
pha mode to"
3700 PRINT "ask if there are any corrections. At this point k2 will return the
graphics"
3710 PRINT "to the screen and k1 will return the alpha mode to the screen."
3720 Blanks=0
3730 IF P=15 THEN GOSUB Pagecrt
3740 PRINT
3750 PRINT "To make corrections, the numbers of ALL incorrect regions are ente
red and the"
3760 PRINT "components erased. When there are no more to be removed, pressing
CONT with"
3770 PRINT "no entry will allow all empty regions to be redefined. A flashing c
ross will"
3780 PRINT "visit each empty region followed by further correction opportunity a
s needed."
3790 PRINT "When the board is correct, the general purpose key definitions are
returned"
3800 PRINT "and the normal key code overlay should be replaced. "
3810 PRINT
3820 Pagenum=2
3830 Blanks=11
3840 IF P=0 THEN GOSUB Pageprt
3850 PRINT " DIP components generally are produced in two different case styl
es, ceramic"
3860 PRINT "or plastic. These are different sizes and this affects the thermal
analysis"
3870 PRINT "performed in THERML. The next section provides several methods to
specify the"
3880 PRINT "case styles for the DIP's. These are: 1) all plastic...2) all ceram
ic..."
3890 PRINT "3) majority ceramic (user specify which are plastic)...4) majority c
eramic (user"
3900 PRINT "specify which are ceramic)...5) user specify case style for each DIP
component."
3910 PRINT "In general, option 3 or 4 require the user to input the number of re
gions that"
3920 PRINT "are either plastic or ceramic and are useful for specifying the styl
e when"
3930 PRINT "when only a few are different. When there is a nearly equal mix, op
tion 5"
3940 PRINT "requires a 1 for plastic style and a 0 for ceramic style. After all
DIP's are"
3950 PRINT "specified, a list of region numbers is displayed on the screen (in
alpha mode)"
3960 PRINT "with the plastic cases in inverse video (numbers black on light back
ground) and"
3970 PRINT "ceramic cases in normal video. Correct as needed and again no corre
ctions is"
3980 PRINT "indicated by pressing CONT Key with no entry."

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3990 IF F=0 THEN 4040
4000 DISP "PRESS CONT WHEN READY FOR ANOTHER PAGE OF INSTRUCTIONS"
4010 PRINT LIN(2)
4020 PAUSE
4030 GOTO 4050
4040 PRINT
4050 PRINT "    The next section concerns the thermally conductive paths that are added "
4060 PRINT "to the circuit board. Both the electrical conductors and any thermal conduction"
4070 PRINT "paths or rails will transfer heat between regions. When any conduction"
4080 PRINT "rails are present, the effects of the electrical leads will be negligible and"
4090 PRINT "ignored. To aid in the modeling of the conduction rails it is necessary to"
4100 PRINT "introduce the concept of a Conduction Path Unit (CPU). Each of the rails is"
4110 PRINT "modeled as containing an integer number CPU's. The width of a CPU is defined "
4120 PRINT "to be .1 mm while the user must define the thickness (mm) and thermal"
4130 PRINT "conductivity (Watts/M-C) of the material that forms the conduction rails."
4140 PRINT "The thermal conductivities of several aluminum alloys and copper are presented"
4150 PRINT "to aid the user. If there are no conduction rails present, the electrical lead"
4160 PRINT "description is entered in the much the same way; thickness (mm), average width"
4170 PRINT "(mm) and the conductivity (Watts/M-C). This will default to 384 Watts/M-C, the"
4180 PRINT "value for copper. This is the most common material for traces on circuit boards."
4190 IF F=0 THEN 4240
4200 PRINT LIN(2)
4210 DISP "PRESS CONT WHEN READY FOR ANOTHER PAGE OF INSTRUCTIONS"
4220 PAUSE
4230 GOTO 4250
4240 PRINT
4250 PRINT "    In the next section the numbers of leads or CPU's that cross the interior"
4260 PRINT "boundaries between regions are entered. The display will alternate between"
4270 PRINT "the graphics and the alpha mode with the flashing cross or cursor moving to the"
4280 PRINT "appropriate location on the board to be defined. The graphics will remain on"
4290 PRINT "the screen for two seconds and then return to the alpha mode for an input line."
4300 PRINT "It will ask for the input of the number of leads or CPU's between two specific"
4310 PRINT "regions; ie if the conduction rail is 6.7 mm wide, there are 67 CPU's in that"
4320 PRINT "path. Special function key 3 (k3) may be used to dump the graphics to the"
4330 PRINT "printer for a hard copy of the graphics picture. It is important to account"
```


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4340 PRINT "for the leads on both sides of the circuit board when entering this number."
4350 PRINT "As before follow all entries with the CONT key. Because of the program flow"
4360 PRINT "in this section, the Back_up option (K0) will not function. Do not attempt to"
4370 PRINT "make corrections or return to a previous section until after all entries have"
4380 PRINT "been made. All corrections will be made in the next section."
4390 PRINT
4400 PRINT " In the thermal model used by the THERMELEX system, all heat is transferred"
4410 PRINT "to the cooling air stream. None of the heat is transferred out the edges of"
4420 PRINT "the circuit board. For this reason, the sides of the regions at the edges"
4430 PRINT "will be labeled with 0 to indicate that no leads or CPU's cross this boundary."
4440 PRINT "When this heat loss from the board edges and connector is neglected, the results"
4450 PRINT "will be conservative. These assumptions may be unacceptable for circuit boards"
4460 PRINT "used in installations where a significant fraction of the total heat dissipated"
4470 PRINT "is conducted away from the board through card guides or connectors."
4480 PRINT
4490 PageNum=3
4500 Blanks=5
4510 IF P=0 THEN GOSUB Pageprt
4520 PRINT " When all regions have been specified, the screen will return to the alpha"
4530 PRINT "mode and ask if any corrections are needed. Use the special functions keys"
4540 PRINT "as required to either return to graphics/alpha or produce a hard copy. Enter"
4550 PRINT "the numbers of the connecting regions that have incorrect values for the numbers"
4560 PRINT "of leads or CPU's. As before, CONT with no entry signals the lack of further"
4570 PRINT "corrections. The physical description of the circuit board is now complete."
4580 PRINT "All that remains is to specify either the component power levels (Watts) or the"
4590 PRINT "junction temperatures for each component."
4600 PRINT
4610 PRINT " When the maximum junction temperatures for the components are specified,"
4620 PRINT "the maximum steady state power level that will result in that temperature is"
4630 PRINT "calculated for each component. When the steady state power of each component"
4640 PRINT "is specified, the steady state junction temperatures are calculated."
4650 PRINT "In either situation it is also necessary to specify the case to junction"
4660 PRINT "thermal resistance Rj_c (Deg C/Watt). The thermal model uses the component"
4670 PRINT "surface temperatures for heat transfer calculations and Rj_c provides the link"

4680 PRINT "between the component power, junction temperature and the surface temperature."
 4690 PRINT "If Rj_c is specified as zero (0) then the case surface temperature will be"
 4700 PRINT "equal to the junction temperature."
 4710 PRINT
 4720 PRINT " After all component power levels or junction temperatures have been set,"
 4730 PRINT "the complete list is displayed in the alpha mode to allow checking and"
 4740 PRINT "changes. Corrections are inserted by entering the incorrect region number then"
 4750 PRINT "entering the correct values in response to the question asked. If desired"
 4760 PRINT "a hard copy of all data for the circuit board will be provided from the printer."
 4770 PRINT
 4780 PRINT " The next section allows recording of the circuit board descriptive data "
 4790 PRINT "on to a mass storage media. This should be done. The recorded data file may be"
 4800 PRINT "accessed at some later time either in BOARDS for editing and changes or"
 4810 PRINT "directly in THERML to perform the thermal analysis. BOARDS will create the "
 4820 PRINT "the necessary data file to record the description but if a data file of"
 4830 PRINT "sufficient size exists, it may be used. All old data in that file will"
 4840 PRINT "be permanently lost. Information concerning the minimum data file size is"
 4850 PRINT "presented by the program to help in this decision. "
 4860 PRINT
 4870 PRINT " Built in error traps throughout the entire THERMELEN system will save the "
 4880 PRINT "user from loss of previous inputs in case of errors. Information about the"
 4890 PRINT "error is presented and using the error message guide on the plastic slide outs"
 4900 PRINT "below the screen, the user may be able to make corrections. When ready, as"
 4910 PRINT "signaled by CONT key, program flow returns to a previous point and operation"
 4920 PRINT "resumes. The data recording section where file names are entered is particularly"
 4930 PRINT "prone to spelling errors or entry of incorrect mass storage unit specifications."
 4940 PRINT "Be careful but remember the system will attempt to catch those inevitable errors"
 4950 PRINT "and act on them before they become fatal."
 4960 PRINT
 4970 PRINT " The end of a cycle through BOARDS is now complete. As the page heading"
 4980 PRINT "that will appear states, WHAT NOW ?. More work with BOARDS is possible. The"
 4990 PRINT "user may either input another circuit board description from the keyboard and"
 5000 PRINT "record that to mass storage; or, he may retrieve a different circuit board"

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5010 PRINT "descriptive data set from mass storage for checking and corrections.
"
5020 PRINT "Another option is to perform the thermal analysis of the circuit board using"
5030 PRINT "the third program in the THERMELEX system, THERML."
5040 PRINT
5050 PageNum=4
5060 Blanks=6
5070 IF P=0 THEN GOSUB Pageprt
5080 PRINT "    Before an explanation of the program flow in THERML, some explanation of"
5090 PRINT "the use of BOARDS to edit previously recorded data files is in order. This"
5100 PRINT "option may be accessed through the use of AUTOST as explained on the first page"
5110 PRINT "of these instructions or the BOARDS program may be directly entered into the"
5120 PRINT "computer with the command:      LOAD ";CHR$(34);"BOARDS:T15,1";CHR$(34);
5130 PRINT "then Press EXECUTE "
5140 PRINT "Of course the appropriate mass storage specifier should be used both here and"
5150 PRINT "when entering the file name for any previously recorded data file. See the "
5160 PRINT "Operating and Programming Manual for the 9845 if the above is not clear."
5170 PRINT
5180 PRINT "    Following the input of the file name that contains the descriptive data,"
5190 PRINT "the data file will be read and all the variables that are normally set from"
5200 PRINT "the keyboard will be defined. The circuit board will be drawn on the screen"
5210 PRINT "in graphics mode and changes to the specific components that occupy the regions"
5220 PRINT "may be made. However; it is not possible to change the number of regions in"
5230 PRINT "any way. This major revision of the board must be done as a new board input."
5240 PRINT "Correction to case styles is next and then the numbers of leads on CPUs"
5250 PRINT "between regions will be labeled on to the graphics picture of the circuit board"
5260 PRINT "Changes will be allowed to the numbers but not the physical sizes of the leads"
5270 PRINT "on CPUs; this also requires a new board input. A list of power levels,"
5280 PRINT "junction temperature and case to junction thermal resistances is presented"
5290 PRINT "for checking and corrections as required. This edited descriptive data set may"
5300 PRINT "then be recorded either back to the same data file or to a new file.
"
5310 PRINT
5320 PRINT "    There are two demonstration data files included in the THERMELEX system."
5330 PRINT "DEMO-I contains a typical circuit board description needed to determine the"
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5340 PRINT "steady state junction temperature (ie component power levels are spe
cified)."
```

5350 PRINT "DEMO-P contains a different circuit board for which maximum powers levels are "

5360 PRINT "determined in the thermal analysis. The use of either of these can be helpful"

5370 PRINT "to familiarize the user with both BOARDS and the last program in t he THERELEX"

5380 PRINT "system, THERML."

5390 PRINT

5400 PRINT " THERML creates the mathematical model, performs the analysis of the circuit"

5410 PRINT "board and produces the output. The variables used in the thermal model are set"

5420 PRINT "using either a data file from mass storage or they are passed in a common block"

5430 PRINT "when THERML is loaded from BOARDS. There are no correction opportunities"

5440 PRINT "for the circuit board descriptive variables in this program."

5450 PRINT

5460 PRINT " Assuming that THERML has been loaded from the What Now option list in "

5470 PRINT "BOARDS, the first input is the inlet temperature(deg C) of the cooling air."

5480 PRINT "After this is entered and printed on the screen, the volumetric air flow"

5490 PRINT "rate (M3/sec) is requested. Since the same set of general purpose special"

5500 PRINT "function keys are valid in this program, the keycode overlay should remain and"

5510 PRINT "k0 (Back-up) may be used to return to a previous question when input errors are"

5520 PRINT "made. The next input is the spacing between the circuit boards for rack mounts."

5530 PRINT "This spacing and the board height determines the size of the imaginary air duct"

5540 PRINT "containing the circuit board. When combined with the amount of air flow for"

5550 PRINT "each circuit board the air velocity and heat transfer correlations are"

5560 PRINT "determined. Since all the power dissipated on the circuit board must be"

5570 PRINT "removed by the air flow, it is important for these values to be as precise"

5580 PRINT "as possible. After the thermal analysis is complete, there will be opportunities"

5590 PRINT "to alter these important air flow parameters and examine the effects on the"

5600 PRINT "output."

5610 PRINT

5620 PageNum=5

5630 Blanks=6

5640 IF P=0 THEN GOSUB Pageprt

5650 PRINT " Before the analysis begins, the convergence criteria must be set. The"

5660 PRINT "analysis consists of assuming a solution then defining a set of simultaneous"

5670 PRINT "equations (one for each region) which are solved for either the power"

5680 PRINT "on the junction temperatures. The results are compared to the previous results"
 5690 PRINT "(the assumed values for the first iteration) and if the largest difference"
 5700 PRINT "between these values is less than a maximum set by the user, the results are"
 5710 PRINT "presented in graphics. If the convergence criteria is not met, the results"
 5720 PRINT "are printed to the screen in alpha mode and another iteration is entered."
 5730 PRINT "The closer to zero one sets the convergence criteria, the longer the process"
 5740 PRINT "takes. Default values for the convergence criteria are .5 Deg C or 1% change in"
 5750 PRINT "power. These typically require 2 to 5 iterations before they are met. Each"
 5760 PRINT "iteration takes 5 to 100 sec to perform depending on the number of regions."
 5770 PRINT "As the solution proceeds the user may view the intermediate results to watch"
 5780 PRINT "the progress."
 5790 PRINT
 5800 PRINT " The final results are written onto a picture of the circuit board with"
 5810 PRINT "each region containing component type, junction temperature, power level and"
 5820 PRINT "case temperature. Empty regions contain only the temperature of the circuit"
 5830 PRINT "board. Those junction temperatures within 5% of the maximum and those power"
 5840 PRINT "levels within 5% of the minimum are starred (++) for easy reference as trouble"
 5850 PRINT "spots. This graphics output is automatically dumped to the printer to insure"
 5860 PRINT "that a hard copy of the results exist."
 5870 PRINT
 5880 PRINT " This completes a cycle through THERML and again the question is What Now ?"
 5890 PRINT "BOARDS may be returned to core, to make changes to the circuit board or"
 5900 PRINT "to enter a new circuit board. Another analysis of the same circuit board"
 5910 PRINT "may be done with a new set of air flow parameters or, a new circuit board"
 5920 PRINT "descriptive data set may be read in from mass storage with THERML."
 5930 PRINT
 5940 PRINT " An additional option is sensitivity analysis. Plots of the maximum"
 5950 PRINT "Tjunc vs. Air Flow Rate or the minimum Power vs. Air Flow Rate may be produced."
 5960 PRINT "A maximum air flow rate is specified and five separate analyses are performed"
 5970 PRINT "and the results plotted and dumped to the printer. The maximum air flow rate"
 5980 PRINT "specified should be an integer multiple of five to make for better looking axes."
 5990 PRINT "It is also possible to produce hard copies of the printed results for each of the"

AUTOST .. DRIVER FOR THERMELEX

```
6000 PRINT "air flow rates. Upon completion of this sensitivity analysis, progr  
am flow"  
6010 PRINT "returns to the option list previously discussed."  
6020 PRINT  
6030 PRINT "      Termination should be done under program control using the final  
option."  
6040 PRINT "This will insure that the standard key definitions are returned and  
that the"  
6050 PRINT "proper graphics parameters are set for the next user of the computer  
."  
6060 PRINT LIN(2),TAB(32),"GOOD LUCK"  
6070 Pagenum=6  
6080 Blanks=16  
6090 IF P=0 THEN GOSUB Pageprt  
6100 PRINTER IS 16  
6110 RETURN
```


APPENDIX C

```

5      !          BOARDS          ..... DATA INPUT AND STORAGE PROGRAM FOR ....
10
15      ! ***** THERMELEX *****
20      !
25      !          A SYSTEM OF PROGRAMS FOR THE HP 9845
30      !
35      !          TO PERFORM THERMAL ANALYSIS OF ELECTRONIC CIRCUIT BOARDS
40      !
45      ! *****
50      ! *
55      ! *
60      ! *          PREPARED AT THE NAVAL POSTGRADUATE SCHOOL MONTEREY CA
65      ! *
70      ! *          R. A. FOLTZ LCDR USN
75      ! *
80      ! *          ||||| BOARDS |||||          ..... JUNE 1980
85      ! *****
90      !
95      OPTION BASE 1
100     PRINTER IS 16
105     COM Map,Names$,Pict1b1$(50),Case$(50),Bd1,Bdh,Scs,Thick_b,Tem_sol,Kb,A1,K1
110     COM SHORT X(50),Y(50),Tj(50),Power(50),Rj_c(50)
115     COM INTEGER Itype(50),N1(4,50),Nxn,Nyn,Nreg
120     SHORT Le(50),We(50)
125     INTEGER Npin(50)
130     DIM S$(70),Mnu$(22)
135     IF Map=0 THEN Start
140     Start_lower: ON Map GOTO Oldpict_connect,Bdpict,Oldpict
145     DISP "MAP= ";Map
150     PAUSE
155     Start: GOSUB Error
160     Start: S$="THERMAL ANALYSIS PROGRAM FOR ELECTRONIC CIRCUIT BOARDS"
165     ON ERROR GOTO Start
170     GOSUB Pagehead
175     PRINT " This program allows the user to input a detailed description of an
180     "electronic"
185     PRINT "circuit board and perform a thermal analysis to predict either the s
190     "eady state"
195     PRINT "temperatures of the components if power levels are given or the comp
200     "onent power"
205     PRINT "level that will result in the steady state temperature specified by
210     "the user."
215     PRINT "The description can come from a data file previously created by this
220     "program"
225     PRINT "or can be entered at this time."
230     Ans$="N"
235     INPUT "DO YOU DESIRE TO RETRIEVE A PREVIOUSLY STORED DESCRIPTION (N OR Y)",
240     Ans$
245     IF Ans$="BACK UP" THEN 160
250     IF (UPC$(Ans$(1,1))="N") OR (UPC$(Ans$(1,1))="Y") THEN 235
255     GOSUB Error
260     GOTO Start
265     IF UPC$(Ans$(1,1))="N" THEN Bdpict
270     GOTO Oldpict
275     Oldpict: GOSUB Error
280     Oldpict: ! THIS SECTION RETRIEVES A BOARD DESCRIPTION OFF A MASS STORAGE DEV
285     ICE
290     ON ERROR GOTO Oldpict

```


BOARDS .. DATA INPUT FOR THERMELEN

```

260 Oldc=PI
265 S$="BOARD DESCRIPTION FROM MASS STORAGE DEVICE"
270 GOSUB Pagehead
275 PRINT "      The data file containing the board description must have been st
ored by "
280 PRINT "this program. Enter the data file name below, be sure to include th
e mass "
285 PRINT "storage unit specifier if needed, eg :T14,:F8,:Y12 etc"
290 EDIT "UNDER WHAT FILE NAME IS THE CIRCUIT BOARD FILED (input or change belo
u)",Name$
295 IF Name$="BACK_UP" THEN 160
300 IF Name$="NULL" THEN Oldpict
305 ASSIGN #5 TO Name$
310 READ #5,1
315 READ #5;Name$,Pic1,b1$,Case$,Bd1,Bdh,Sca,Nar,Nyn,Nneg,Thick_b,Kb,A1,K1,Tem_
ol
320 FOR I=1 TO Nneg
325 READ #5;Itype(I),X(I),Y(I),Tj(I),Pow(I),Rj_c(I)
330 FOR J=1 TO 4
335 READ #5;H1(J,I)
340 NEXT J
345 NEXT I
350 Oldpict_connect: GOSUB Board_pict
355 GRAPHICS
360 FOR I=1 TO Nneg
365 IF I=1 THEN 385
370 IF I<Nn+1 THEN 380
375 IF (Itype(I)=10) AND (Itype(I-Nn)=10) THEN 400
380 IF (Itype(I)=9) AND (Itype(I-1)=9) THEN 400
385 IF Itype(I)=0 THEN GOSUB Empty
390 IF Itype(I)=0 THEN 400
395 ON Itype(I) GOSUB Hdip14,Vdip14,Hdip16,Vdip16,Hdip24,Vdip24,Ennolde,Ennolde
,Hdip40,Vdip40,Flat16,Flat24,Flat40,Flat64
400 NEXT I
405 GOSUB Bd_cha
410 IF Ans$="BACK_UP" THEN Oldpict
415 GOSUB Case_top
420 IF Ans$="BACK_UP" THEN 405
425 GOSUB Leads_oTd
430 IF Ans$="BACK_UP" THEN 415
435 GOSUB Leads_cha
440 IF Ans$="BACK_UP" THEN 425
445 GOSUB Tempin
450 IF Ans$="BACK_UP" THEN 435
455 GOSUB Stow
460 IF Ans$="BACK_UP" THEN 445
465 GOSUB What_now
470 IF Ans$="BACK_UP" THEN 455
475 GOTO Start_over
480 Bdpicte: GOSUB Error
485 Bdpict:!! THIS SECTION IS THE NORMAL ENTRY POINT FOR NEW BOARD INPUT
490 ON ERROR GOTO Bdpicte
495 Oldc=0
500 S$="KEYBOARD INPUT OF CIRCUIT BOARD DESCRIPTION"
505 GOSUB Pagehead
510 PRINT "      This routine draws a blank circuit board and divides it into regi
ons of "
515 PRINT "interest as determined by the user. There are a maximum of 50 regions
available"

```


BOARDS .. DATA INPUT FOR THERMELEN

```

520 PRINT "with one component/region. The circuit board is then presented on the
525 PRINT "CRT either normal size or scaled up or down by some integer if larger
    or smaller"
530 PRINT "than 120mm by 170mm. The specific components are selected with the use
    of keys"
535 PRINT "in the upper right corner of the keyboard. If you do not have a key
    code "
540 PRINT "overlay for the keys the program will provide one for you. Information
    to be "
545 PRINT "used in the thermal analysis routine is entered in this section of the
    program."
550 PRINT "You will have the option of recording the board description onto mass
    storage."
555 PRINT
560 PRINT "Conductivity of the board will default to .2942 Watts/in-degK with no
    entry."
565 PRINT LIN(1),"NOTE : LENGTH IS DEFINED TO BE IN THE DIRECTION OF AIR FLOW
    "
570 MAT I%type=ZER
575 Ans#="NULL"
580 INPUT "WHAT IS THE LENGTH OF THE BOARD IN MILLIMETERS",Ans#
585 IF Ans#="BACK UP" THEN Start
590 IF Ans#="NULL" THEN 575
595 Bdl=ABS(VAL(Ans#))
600 PRINT LIN(1),TAB(10),"LENGTH =";Bdl;" mm"
605 Scalex=INT(Bdl/171)+1
610 IF Bdl<171/2 THEN Scalex=.5
615 Ans#="NULL"
620 INPUT "WHAT IS THE HEIGHT OF THE BOARD IN MILLIMETERS",Ans#
625 IF Ans#="BACK UP" THEN Bdpic+
630 IF Ans#="NULL" THEN 615
635 Bdh=ABS(VAL(Ans#))
640 PRINT LIN(1),TAB(10),"HEIGHT =";Bdh;" mm"
645 Scaley=INT(Bdh/121)+1
650 IF Bdh<121/2 THEN Scaley=.5
655 Sca=MAX(Scalex,Scaley) ! SCALE FACTOR TO FILL CRT DISPLAY
660 IF Sca=1 THEN 680
665 IF Sca<1 THEN PRINT LIN(2),"+++NOTE+++ DUE TO SMALL SIZE OF THE BOA
RD CRT DISPLAY WILL BE 2X SIZE"
670 IF Sca>1 THEN PRINT LIN(2),"+++NOTE+++ DUE TO LARGE SIZE OF THE BOA
RD CRT DISPLAY WILL BE 1 /";Sca;"SIZE"
675 Ans#="NULL"
680 INPUT "WHAT IS THE NUMBER OF DIVISIONS (REGIONS) IN THE HORIZONTAL DIRECTIO
N",Ans#
685 IF Ans#="BACK UP" THEN 615
690 IF Ans#="NULL" THEN 675
695 Nxr=ABS(VAL(Ans#))
700 PRINT LIN(1),TAB(10),"# Xreg =";Nxr
705 Ans#="NULL"
710 INPUT "WHAT IS THE NUMBER OF DIVISIONS (REGIONS) IN THE VERTICAL DIRECTION"
,Ans#
715 IF Ans#="BACK UP" THEN 675
720 IF Ans#="NULL" THEN 705
725 Nyr=ABS(VAL(Ans#))
730 PRINT LIN(1),TAB(10),"# Yreg =";Nyr
735 Nreg=Nxr+Nyr ! Nreg = NUMBER OF REGIONS
740 IF Nreg/51 THEN 770

```


BOARDS .. DATA INPUT FOR THERMELEN

```

745 BEEP
750 PRINT PAGE, LINK(15), SPAC(30), "TOO MANY REGIONS"
755 WAIT 1000
760 GOSUB Errin
765 GOTO Bdpict
770 Ans$="NULL"
775 INPUT "WHAT IS THE THICKNESS OF THE BOARD? (mm)", Ans$
780 IF Ans$="BACK_UP" THEN 705
785 IF Ans$="NULL" THEN 770
790 Thick_b=ABS(VAL(Ans$))
795 PRINT LINK(1), TAB(10), "Thick_b="; Thick_b; " mm"
800 Ans$=".2942"
805 EDIT "WHAT IS THE THERMAL CONDUCTIVITY OF THE BOARD? (WATTS/M -deg K)", Ans$
810 IF Ans$="BACK_UP" THEN 755
815 Kb=ABS(VAL(Ans$))
820 PRINT LINK(1), TAB(10), "Cond_b="; Kb
825 EDIT "INPUT A SHORT (<50 CHARACTERS) WORD DESCRIPTION OF THE CIRCUIT BOARD
HERE ", Pict1b1$
830 IF Pict1b1$="BACK_UP" THEN 800
835 IF LEN(Pict1b1$)<51 THEN 850
840 GOSUB Errin
845 GOTO 825
850 GOSUB Board_pict
855 GOSUB Graphkey
860 IF Ans$="BACK_UP" THEN Bdpict
865 GOSUB Ed_cha
870 IF Ans$="BACK_UP" THEN 850
875 GOSUB Case_top
880 IF Ans$="BACK_UP" THEN 865
885 GOSUB Leads
890 IF Ans$="BACK_UP" THEN 875
895 GOTO 435
900 Board_pict: GOSUB Errin
905 Board_pict: ! THIS SECTION PLACES A BLANK BOARD ON THE SCREEN
910 ON ERROR GOTO Board_pict
915 PLOTTER IS "GRAPHICS"
920 GRAPHICS
925 MSCALE 0,10
930 CSIZE 3
935 LOG 5
940 MOVE 26,130
945 LABEL "----air flow----> "
950 Bdh=Bdh/Scs
955 Bdl=Bdl/Scs
960 LOG 6
965 LDIR PI/2
970 MOVE 175,70
975 IF Scs>1 THEN LABEL "THIS PICTURE IS 1/"&VAL(Scs)&" SIZE"
980 IF Scs<1 THEN LABEL "THIS PICTURE IS 2X SIZE"
985 LOG 5
990 LDIR 0
995 MOVE 92-LEN(Pict1b1$)/2,135
1000 LABEL USING "K";Pict1b1$
1005 MOVE 0,0
1010 DRAW 0,Bdh
1015 DRAW Bdl,Bdh
1020 DRAW Bdl,0
1025 DRAW 0,0

```

! END OF Bdpict

BOARDS .. DATA INPUT FOR THERMELEN

```

1030 LINE TYPE 3
1035 Lr=Bdl/Nnr
1040 Hr=Bdh/Nnr
1045 FOR I=1 TO Nnr-1
1050 MOVE I+Lr,0
1055 DRAW I+Lr,Bdh
1060 NEXT I
1065 FOR I=1 TO Nnr-1
1070 MOVE 0,I+Hr
1075 DRAW Bdl,I+Hr
1080 NEXT I
1085 LINE TYPE 1
1090 LOG 5
1095 Nr=0
1100 FOR J=Nnr TO 1 STEP -1
1105 FOR I=1 TO Nr
1110 Nr=Nr+1
1115 X(Nr)=Lr+I-1+Lr*2
1120 Y(Nr)=(J-1)+Hr+(1+Hr*2)
1125 MOVE X(Nr),Y(Nr)
1130 LABEL USING "K";VALI(Nr)
1135 NEXT I
1140 NEXT J
1145 Bdh=Bdh+Scs
1150 Bdl=Bdl+Scs
1155 WAIT 1500
1160 EXIT GRAPHICS
1165 RETURN
1170 Graphkey: GOSUB Error
1175 Graphkey: HERE IS SUBROUTINE TO ALLOW INPUT OF BOARD DESCRIPTION FROM KEYS
DATA INPUT
1180 ON ERROR GOTO Graphkey
1185 Ans#=""
1190 S#="KEY CODE OVERLAY"
1195 GOSUB Pagehead
1200 PRINT " This section allows the components to be defined and drawn on the
screen"
1205 PRINT "using the keys in the upper right corner of the keyboard. The previ-
ous key"
1210 PRINT "definitions are not valid while entering the components but will
be"
1215 PRINT "during later portions of this program. As the flashing cursor moves
to each"
1220 PRINT "region in numerical order press the corresponding key and wait for th-
e cursor to"
1225 PRINT "appear at the next region. All regions must be defined even if with
k0=>EMPTY."
1230 PRINT
1235 PRINT " NOTE: k11-k14 refer to chip carriers or flat packs."
1240 PRINT
1245 PRINT " If you do not have a plastic key code overlay filled in (HP part
#7120-6164), I will make a paper one for you."
1250 Ans#=""
1255 INPUT "DO YOU NEED A PAPER OVERLAY (N or Y)?",Ans#
1260 IF Ans#="BACK_UP" THEN RETURN
1265 IF UPC#Ans#(1,1)="" THEN 1320
1270 PRINTER IS 0
1275 PRINT SPAC(10),"TEAR OFF FOR COMPONENT DEFINITION KEY CODE OVERLAY",LIN(2
)

```


BOARDS .. DATA INPUT FOR THEPMELEN

```

1280 PRINT " | EMPTY | HOPIZ | VERT | HORIZ | VERT | HORIZ | VERT | "
1285 PRINT " | (k6) | DIP14 | DIP14 | DIP16 | DIP16 | DIP24 | DIP24 | " PLACE A
BOVE KEYS"
1290 PRINT "TEAR HERE -----THEN PRESS CON
T ---"
1295 PRINT LIN(1)
1300 PAUSE
1305 PRINT " | (k8) | HORIZ | VERT | FLAT | FLAT | FLAT | FLAT | " PLACE
BELOW KEYS "
1310 PRINT " | | DIP40 | DIP40 | 16 PIN | 24 PIN | 40 PIN | 64 PIN | "
1315 PRINT LIN(4)
1320 PRINTER IS 16
1325 ! NOTE THAT THE KEY# IS THE CODE FOR TYPE OF ELEMENT STORED IN Itype(I)
1330 ON KEY #0 GOTO Empty
1335 ON KEY #1 GOTO Hdip14
1340 ON KEY #2 GOTO Vdip14
1345 ON KEY #3 GOTO Hdip16
1350 ON KEY #4 GOTO Vdip16
1355 ON KEY #5 GOTO Hdip24
1360 ON KEY #6 GOTO Vdip24
1365 ON KEY #7 GOTO 1435
1370 ON KEY #8 GOTO 1435
1375 ON KEY #9 GOTO Hdip40
1380 ON KEY #10 GOTO Vdip40
1385 ON KEY #11 GOTO Flat16
1390 ON KEY #12 GOTO Flat24
1395 ON KEY #13 GOTO Flat40
1400 ON KEY #14 GOTO Flat64
1405 IF Oldc=PI THEN RETURN
1410 GRAPHICS
1415 FOR I=1 TO Nneg
1420 IF Itype(I)=10 THEN Nextc
1425 Loop: MOVE X(I),Y(I)
1430 POINTER X(I),Y(I),2
1435 ! THIS IS AN ENDLESS LOOP TO ALLOW FOR USE OF THE PRIORITY INTERRUPT KEYS
1440 GOTO Loop
1445 Nextc: IF Reg_cha<0 THEN RETURN
1450 IF I<Nneg THEN 1475
1455 IF Oldc<>PI THEN WAIT 100+Nneg*1.5
1460 POINTER 0,0,2
1465 EXIT GRAPHICS
1470 RETURN
1475 NEXT I
1480 Empty:GOSUB Eraseum
1485 Itype(I)=Npin(I)=We(I)=Le(I)=0
1490 GOTO Nextc
1495 Hdip14:GOSUB Eraseum
1500 Npin(I)=14
1505 IF Itype(I)=2 THEN LDIP PI*2
1510 LABEL USING "K":DIP14"
1515 We(I)=We+25*25.4 ! ACTUAL WIDTH IN mm
1520 Le(I)=Le+725*25.4 ! ACTUAL LENGTH IN mm
1525 IF (Itype(I)=1) OR (Itype(I)=0) THEN 1545
1530 Temp_dim=We(I) ! HERE LENGTH AND WIDTH TRANSPOSED SUCH THAT LENGTH
1535 We(I)=We*Le(I) ! IS DEFINED TO BE IN THE DIRECTION OF AIR-FLOW
1540 Le(I)=Le*Temp_dim
1545 IF Itype(I)=0 THEN Itype(I)=1
1550 Drawdip: ! THIS SECTION WILL DRAW ALL THE DIP FIGURES ON THE CRT IF Npin<28

```


BOARDS .. DATA INPUT FOR THERMELEX

```

1555 Le=Le/Scs
1560 We=We/Scs
1565 MOVE X(I)-Le/2,Y(I)-We 2
1570 DRAW X(I)-Le 2,Y(I)+We 2
1575 DRAW X(I)+Le 2,Y(I)+We 2
1580 DRAW X(I)+Le 2,Y(I)-We 2
1585 DRAW X(I)-Le 2,Y(I)-We 2
1590 LDIP 0
1595 GOTO Nextr ! End of Draw_dip
1600 Vdip14:Itype(I)=2
1605 GOTO Hdip14
1610 Hdip16:GOSUB Eraseenum
1615 Npin(I)=16
1620 IF Itype(I)=4 THEN LDIP PI/2
1625 LABEL USING "K";"DIP16"
1630 We(I)=We*.25+25.4 ! WIDTH IN mm
1635 Le(I)=Le*.325+25.4 ! LENGTH IN mm
1640 IF Itype(I)<>4 THEN Itype(I)=3
1645 IF Itype(I)=4 THEN Drawdip
1650 Temp_dim=We(I)
1655 We(I)=We=Le(I)
1660 Le(I)=Le=Temp_dim
1665 GOTO Drawdip ! End of Hdip16
1670 Vdip16:Itype(I)=4
1675 GOTO Hdip16
1680 Hdip24:GOSUB Eraseenum
1685 Npin(I)=24
1690 IF Itype(I)=6 THEN LDIP PI/2
1695 LABEL USING "K";"DIP 24"
1700 We(I)=We*.55+25.4
1705 Le(I)=Le*1.25+25.4
1710 IF Itype(I)<>6 THEN Itype(I)=5
1715 IF Itype(I)<>6 THEN Drawdip
1720 Temp_dim=We(I)
1725 We(I)=We=Le(I)
1730 Le(I)=Le=Temp_dim
1735 GOTO Drawdip ! End of Hdip24
1740 Vdip24:Itype(I)=6
1745 GOTO Hdip24
1750 Hdip40:IF (I MOD Npin=0) OR (Itype(I+1)=10) AND (Reg_cha=0) THEN Loop
1755 GOSUB Eraseenum
1760 I=Ih+1
1765 GOSUB Eraseenum
1770 I=I-1
1775 Npin(I)=Npin(Ih)=20 ! THIS IS FOR EACH HALF OF THE 40 PINS
1780 Itype(I)=Itype(Ih)=9
1785 MOVE X(I)+Ln/2,Y(I)
1790 LABEL USING "K";"DIP40"
1795 We(I)=We(Ih)=We*.6+25.4
1800 Le(I)=Le(Ih)=Le*25.4 ! THIS IS FOR EACH HALF IN EACH REGION
1805 We=We/Scs
1810 Le=Le/Scs
1815 MOVE X(I)+Ln/2-Le,Y(I)+We/2
1820 DRAW X(I)+Ln/2-Le,Y(I)-We/2
1825 DRAW X(I)+Ln/2+Le,Y(I)-We/2
1830 DRAW X(I)+Ln/2+Le,Y(I)+We/2
1835 DRAW X(I)+Ln/2-Le,Y(I)+We/2
1840 I=Ih

```

(7)

BOARDS .. DATA INPUT FOR THERMELEN

```

1845 GOTO Nextr
1850 Vdip40:IF I=Ncr`Nreg THEN 1425
1855 GOSUB Eraseum
1860 I=Ih+I+Ncr
1865 GOSUB Eraseum
1870 I=I+Ncr
1875 Npin(I)=Npin(Ih)=20      ! THIS IS FOR THE HALF OF THE 40 PINS IN EACH REGION
1880 Itype(I)=Itype(Ih)=10
1885 LDIR PI/2
1890 MOVE X(I),Y(I)-Hr/2
1895 LABEL USING "K";"DIP40"
1900 LDIR 0
1905 We(I)=We(Ih)=We=.6+25.4
1910 Le(I)=Le(Ih)=Le=25.4      ! THIS IS FOR HALF
1915 We=We/Scs
1920 Le=Le/Scs
1925 MOVE X(I)+We 2,Y(I)-Hr/2+Le
1930 DRAW X(I)-We 2,Y(I)-Hr/2+Le
1935 DRAW X(I)-We/2,Y(I)-Hr/2-Le
1940 DRAW X(I)+We/2,Y(I)-Hr/2-Le
1945 DRAW X(I)+We 2,Y(I)-Hr/2+Le
1950 LDIR 0
1955 Temp_dim=Le(I)HERE TRANSPOSE Le AND We TO MAINTAIN LENGTH DEFF WITH AIR
1960 Le(I)=Le(Ih)=We(I)
1965 We(I)=We(Ih)=Temp_dim
1970 GOTO Nextr
1975 Flat16:Itype(I)=11
1980 GOSUB Eraseum
1985 Npin(I)=16
1990 LABEL USING "K";"16"
1995 Le=We=We(I)=Le(I)=4.57
2000 GOTO Drawdip
2005 Flat24:Itype(I)=12
2010 GOSUB Eraseum
2015 Npin(I)=24
2020 LABEL USING "K";"24"
2025 Le=We=We(I)=Le(I)=7.75
2030 GOTO Drawdip
2035 Flat40:Itype(I)=13
2040 GOSUB Eraseum
2045 Npin(I)=40
2050 LABEL USING "K";"40"
2055 Le=We=We(I)=Le(I)=12.19
2060 GOTO Drawdip
2065 Flat64:Itype(I)=14
2070 GOSUB Eraseum
2075 Npin(I)=64
2080 LABEL USING "K";"FLAT64"
2085 Le=We=We(I)=Le(I)=18.29
2090 GOTO Drawdip
2095 !
2100 Eraseum: ! HERE WE MOVE THE REGION NUMBER TO THE UPPER LEFT CORNER
2105 CSIZE 3
2110 MOVE X(I),Y(I)
2115 PEN -1
2120 LABEL USING "K";I
2125 CSIZE 2.5/Scs
2130 IF Reg_cha=0 THEN PEN 1

```

! END OF COMPONENT DEFFINITIONS

BOARDS .. DATA INPUT FOR THEMEXLEX

```

2135 MOVE X(I)/-.4+Ln.Y(I)+.4+Hr
2140 LABEL USING "K";I
2145 MOVE X(I),Y(I)
2150 CSIZE 3.4/Sca
2155 RETURN
2160 !
2165 Bd_chae:GOSUB Error
2170 Bd_cha: THIS ROUTINE ALLOWS FOR CHANGE OF TYPE FOR SPECIFIED COMPONENTS
2175 ON ERROR GOTO Bd_chae
2180 S$="CHANGE COMPONENTS"
2185 GOSUB Pagehead
2190 PRINT " This section allows corrections to the components on the circuit
board."
2195 PRINT "However; you may not change the circuit board itself. You will first
remove"
2200 PRINT "all unwanted components (up to 10) by entering the region number on
the picture."
2205 PRINT "When removing any component which requires two spaces, use the lower
region num."
2210 PRINT "Entering a 0 or pressing CONT with no entry will allow program to
continue"
2215 PRINT "with the section that allows definition of components in all empty
spaces."
2220 PRINT
2225 PRINT "Remember to allow space for the larger components that require two r
egions. "
2230 Itt=0
2235 Again: Itt=Itt+1
2240 Ans$="0"
2245 INPUT "ENTER THE REGION NUMBER TO REMOVE COMPONENT (DEFAULT=0 =>NONE).",An
s$
2250 IF Ans$="BACK_UP" THEN RETURN
2255 Reg_cha=VAL(Ans$)
2260 IF Reg_cha=0 THEN Add_comp
2265 IF (Reg_cha>0) AND (Reg_cha.Nneg+1) THEN 2280
2270 GOSUB Errin
2275 GOTO Again
2280 Reg_cha(Itt)=Reg_cha
2285 GOSUB Erase_comp
2290 Reg_cha=0
2295 IF Itt<=10 THEN Again
2300 S$="MAXIMUM NUMBER OF REGIONS"
2305 GOSUB Pagehead
2310 PRINT " There are 10 changes to accomplish at this point and to avoid pro
blems you"
2315 PRINT "must redefine the board."
2320 PRINT LIN(3),SPA(15),"Press CONT "
2325 GOSUB Add_comp
2330 GOTO Bd_cha
2335 Erase_comp: THIS SECTION REMOVE UNWANTED COMPONENT TO ALLOW CHANGE
2340 GRAPHICS
2345 PEN -1
2350 I=Reg_cha
2355 IF Itype(Reg_cha)=0 THEN 2365
2360 ON Itype(I) GOSUB Hdip14,Vdip14,Hdip16,Vdip16,Hdip24,Vdip24,Enrolde,Enrolde
,Hdip40,Vdip40,Flat16,Flat24,Flat40,Flat64
2365 PEN 1
2370 GOSUB Empty

```


BOARDS .. DATA INPUT FOR THERMELE

```

2375 IF I<2 THEN 2400
2380 IF (Itype(I)=9) AND (Itype(I)=9) THEN 2390
2385 GOTO 2400
2390 I=I-1
2395 GOSUB Empty
2400 IF I<Nxr+1 THEN 2420
2405 IF Itype(I-Nxr)<>10 THEN 2420
2410 I=I-Nxr
2415 GOSUB Empty
2420 WAIT 500
2425 EXIT GRAPHICS
2430 RETURN
2435 Add_comp: THIS SECTION ALLOWS ADDITION OF COMPONENTS TO EMPTY SPACES
2440 IF Itt<2 THEN 2475
2445 IF Olde=PI THEN GOSUB Graphkey
2450 FOR I=1 TO Nnrg
2455 IF Itype(I)<>0 THEN 2470
2460 POINTER X(I),Y(I),2
2465 GOTO 2460
2470 NEXT I
2475 FOR I=1 TO 15
2480 OFF KEY #I
2485 NEXT I
2490 EXIT GRAPHICS
2495 RETURN
2500 ! END OF ADD_COMP
2505 Case_type:GOSUB Error
2510 Case_type: THIS SECTION ALLOWS THE USER TO SPECIFY THE CASE TYPE FOR DIPs
2515 ON ERROR GOTO Case_type
2520 IF (Olde=PI) AND (Itt<2) THEN GOTO Case_ons
2525 ! BUT FIRST MUST TELL THE USER TO CHANGE THE KEY-CODE OVERLAY
2530 S$="CHANGE OF THE SPECIAL FUNCTION KEYS"
2535 GOSUB Pagehead
2540 PRINT LINK(10),SPAC(10),"REMOVE THE KEY CODE OVERLAY FOR COMPONENT INPUT"
2545 PRINT LINK(1),SPAC(10),"REPLACE THE GENERAL PURPOSE KEY CODE OVERLAY"
2550 DISP SPAC(25),"PRESS CONT WHEN READY"
2555 PAUSE
2560 S$="TYPE OF DIP PACKAGE"
2565 GOSUB Pagehead
2570 PRINT " Dual inline packages (DIPs) generally come in either an injection
n molded"
2575 PRINT "plastic case or a ceramic sandwich case. The style of case construction
affects"
2580 PRINT "the heat transfer and must be known for the thermal model."
2585 PRINT
2590 PRINT "The methods of specifying the types of cases are listed below."
2595 PRINT TAB(15);"THESE APPLY TO THE DIPs ONLY"
2600 PRINT LINK(2)
2605 PRINT TAB(10);"1. ALL CERAMIC"
2610 PRINT TAB(10);"2. ALL PLASTIC"
2615 PRINT TAB(10);"3. MAJORITY CERAMIC (USER SPECIFY WHICH ARE PLASTIC)"
2620 PRINT TAB(10);"4. MAJORITY PLASTIC (USER SPECIFY WHICH ARE CERAMIC)"
2625 PRINT TAB(10);"5. USER SPECIFY CASE STYLE FOR EACH DIP COMPONENT"
2630 Ans$="1"
2635 INPUT "ENTER YOUR CHOICE (1,2,3,4,5)",Ans$
2640 IF Ans$<>"BACK UP" THEN 2670
2645 PRINT LINK(20),SPAC(20),"UNABLE TO BACK UP WITHOUT LOSING THE BOARD".LINK(5)
2650 BEEP

```


BOARDS .. DATA INPUT FOR THERMELEN

```

2655 DISP "Press CONT when ready to continue"
2660 PAUSE
2665 GOTO Case_type
2670 Ans=VAL(Ans#)
2675 IF (Ans<1) OR (Ans>5) THEN Case_type
2680 ON Ans GOSUB Cere,Plas,Mcere,Mptas,Anv
2685 Case_cha:$(="CORRECTIONS TO CASE STYLE FOR DIP PACKAGES"
2690 GOSUB Pagehead
2695 PRINT "      On the screen below is a line that represents the case type for
all regions."
2700 PRINT "Those regions that contain a plastic cased component are shown in in
verse video"
2705 PRINT "<1> while all others are shown in normal video <1>."
2710 PRINT
2715 PRINT "To make corrections enter the region # that is incorrect, if no chang
es no entry.",LINK(1)
2720   FOR I=1 TO Nreg
2725     IF I MOD 10=1 THEN PRINT SPA(10);
2730     IF (Case$(I,I)="0") AND (I>10) THEN PRINT I;SPA(1);
2735     IF (Case$(I,I)="0") AND (I<10) THEN PRINT SPA(1);I;SPA(1);
2740     IF (Case$(I,I)="1") AND (I>10) THEN PRINT CHR$(129);I;CHR$(128);SPA(1)
;
2745     IF (Case$(I,I)="1") AND (I<10) THEN PRINT CHR$(129);" ";I;CHR$(128);SPA
(1);
2750     IF I MOD 10=0 THEN PRINT LINK(1)
2755     NEXT I
2760     PRINT
2765     Ans#="NULL"
2770     INPUT "ENTER REGION # TO CHANGE OR PRESS CONT WITH NO ENTRY IF OK",Ans#
2775     IF (Ans#="NULL") OR (Ans#="BACK_UP") THEN RETURN
2780     Reg1=VAL(Ans#)
2785     IF (Reg1=0) AND (Reg1=Nreg) THEN 2800
2790     GOSUB Errin
2795     GOTO Case_cha
2800     Case$(Reg1,Reg1)=VAL$(INT((VAL$(Case$(Reg1,Reg1))+1) MOD 2))
2805     GOTO Case_cha
2810     !
2815     Cere: ! ALL CERAMIC CASES
2820     FOR I=1 TO Nreg
2825     Case$(I,I)="0"
2830     NEXT I
2835     RETURN
2840     !
2845     Plas: ! ALL PLASTIC CASES
2850     FOR I=1 TO Nreg
2855     Case$(I,I)="1"
2860     NEXT I
2865     RETURN
2870     !
2875     Mcere: $$(="MAJORITY CERAMIC ... SPECIFY WHICH ARE PLASTIC"
2880     GOSUB Pagehead
2885     FOR I=1 TO Nreg
2890     Case$(I,I)="0"
2895     NEXT I
2900     Ans#="NULL"
2905     INPUT "ENTER THE NUMBER OF PLASTIC COMPONENTS",Ans#
2910     IF Ans#="BACKUP" THEN Case_type
2915     Ans=VAL(Ans#)

```


BOARDS .. DATA INPUT FOR THERMELEN

```

2920 IF (Ans=0) AND (Ans<Nreg+1) THEN 2935
2925 GOSUB Errin
2930 GOTO Mcere
2935 IF Ans=Nreg THEN Plas
2940   FOR I=1 TO Ans
2945     Ans$="NULL"
2950     INPUT "ENTER THE REGION NUMBER THAT CONTAINS A PLASTIC COMPONENT",Ans$
2955     IF Ans$="BACK UP" THEN Mcere
2960     Reg1=VAL(Ans$)
2965     IF (Reg1>0) AND (Reg1<Nreg+1) THEN 2980
2970     GOSUB Errin
2975     GOTO 2950
2980     Case$(Reg1,Reg1)="1"
2985     NEXT I
2990 RETURN                                     ! END OF Mcere
2995 !
3000 Mplaz: S$="MAJORITY PLASTIC ... SPECIFY WHICH ARE CERAMIC"
3005 GOSUB Pagehead
3010   FOR I=1 TO Nreg
3015     Case$(I,I)="1"
3020     NEXT I
3025     Ans$="NULL"
3030     INPUT "ENTER THE NUMBER OF CERAMIC COMPONENTS",Ans$
3035     IF Ans$="BACKUP" THEN Case_typ
3040     Ans=INT(VAL(Ans$))
3045     IF (Ans=0) AND (Ans<Nreg+1) THEN 3060
3050     GOSUB Errin
3055     GOTO Mplaz
3060     IF Ans=Nreg THEN Cere
3065     FOR I=1 TO Ans
3070       Ans$="NULL"
3075       INPUT "ENTER THE REGION NUMBER THAT CONTAINS A CERAMIC COMPONENT",Ans$
3080       IF Ans$="BACK UP" THEN Mplaz
3085       IF (Reg1>0) AND (Reg1<Nreg+1) THEN 3100
3090       GOSUB Errin
3095       GOTO 3075
3100       Case$(Reg1,Reg1)="0"
3105       NEXT I
3110 RETURN                                     ! END OF Mplaz
3115 !
3120 Any: ! EACH REGION MUST HAVE ITS DIP SPECIFIED
3125   FOR I=1 TO Nreg
3130     IF (Itype(I)<1) OR (Itype(I)>10) THEN 3160
3135     DISP "IDENTIFY CASE TYPE FOR REGION #":I;"(ENTER 1 FOR PLASTIC AND 0 FO
R OTHER)";
3140     INPUT Case$(I,I)
3145     IF (Case$(I,I)="1") OR (Case$(I,I)="0") THEN 3160
3150     GOSUB Errin
3155     GOTO 3135
3160     NEXT I
3165 RETURN                                     ! END OF Any
3170 !
3175 What_now: ! THIS SECTION IS THE FINAL SECTION
3180 S$="WHAT NOW ?"
3185 GOSUB Pagehead
3190 PRINT " You have completed one cycle through BOARDS and have the follow
ing options:"
3195 PRINT LINK(1),TAB(10),"1. PERFORM THERMAL ANALYSIS ON ";Name$;" USING THERM
L."

```


BOARDS .. DATA INPUT FOR THERMLEX

```

3200 PRINT LIN(1),TAB(10),"2. INPUT ANOTHER CIRCUIT BOARD DESCRIPTION FROM KEYBO
ARD."
3205 PRINT LIN(1),TAB(10),"3. INPUT ANOTHER CIRCUIT BOARD DESCRIPTION FROM MASS
STORAGE."
3210 PRINT LIN(1),TAB(10),"4. TERMINATE."
3215 !
3220 Ans$="1"
3225 INPUT "YOUR CHOICE (1,2,3,4)",Ans$
3230 IF Ans$="BACK UP" THEN RETURN
3235 Ans=ABS(INT(VAL Ans$))
3240 IF Ans<5 THEN 3255
3245 GOSUB Errin
3250 GOTO 3220
3255 ON Ans GOTO Therml,Fedo,Fedo,Ende
3260 Therml:DISP "WORKING LOADING THERML TO PERFORM ANALYSIS OF ";Name$
3265 LOAD "THERML",85
3270 STOP
3275 !
3280 Redo: Map=Ans
3285 RETURN
3290 !
3295 Ende:PRINT PAGE,LIN(20),SPA(10),"NORMAL TERMINATION "
3300 DISP "WORKING LOADING STANDARD KEY DEFINITIONS"
3305 GCLEAR
3310 LOAD KEY "STDKEY"
3315 END ! END OF What_now
3320 !
3325 Pagehead: ! THIS SECTION PLACES DESIRED HEADING ON A BLANK CRT
3330 PRINTER IS 18
3335 PRINT PAGE,TAB(34-LEN(S$)/2);"*** ";CHR$(132);S$;CHR$(128);" ***",LIN(2)
3340 RETURN ! END OF PAGEHEAD
3345 !
3350 Errin: ! THIS SECTION ALERTS THE USER TO AN ATTEMPT TO INPUT BAD DATA
3355 BEEP
3360 DISP "INPUT OUT OF RANGE.....TRY AGAIN"
3365 WAIT 1500
3370 BEEP
3375 WAIT 1000
3380 BEEP
3385 RETURN
3390 ! END OF Errin
3395 !
3400 Leadse:GOSUB Erron
3405 Leads: ! THIS SECTION ALLOWS THE INPUT OF THE NUMBER OF LEADS BETWEEN REGION
S
3410 ON ERROR GOTO Leadse
3415 S$="ELECTRICAL LEADS OR OTHER CONDUCTION PATHS"
3420 GOSUB Pagehead
3425 PRINT " All circuit boards have thermally conductive materials applied t
o their "
3430 PRINT "surface either in the form of electrical leads or as thermal conduct
ion paths."
3435 PRINT "Heat will be transferred through these materials between the regions
."
3440 PRINT "if there are conduction paths (rails) present, they will have a much
larger"
3445 PRINT "effect than the electrical leads and the electrical leads will be ne
glected "

```


BOARDS .. DATA INPUT FOR THERMELEX

```

3450 PRINT "in the thermal model."
3455 Ans#="N"
3460 INPUT "ARE THERE METAL CONDUCTION PATHS PRESENT (N or Y)",Ans#
3465 IF Ans#="BACK_UP" THEN RETURN
3470 IF UPC$(Ans#[1,1])="N" THEN Leads_size
3475 IF UPC$(Ans#[1,1])="Y" THEN 3490
3480 GOSUB Errin
3485 GOTO Leads
3490 S#="CONDUCTION FAILS"
3495 A1#="CPU's"
3500 GOSUB Pagehead
3505 PRINT " Thermal conduction rails are much wider and thicker than the ele
ctrical"
3510 PRINT "Leads plated onto the circuit board. The thickness is generally uni
form,"
3515 PRINT "however; the rails are typically not of uniform width. It is theref
ore"
3520 PRINT "necessary to define a concept of Conduction Path Units (CPU's). The
rail width"
3525 PRINT "will be modeled in terms of an integer number of CPU's. You will
be asked to"
3530 PRINT "input the thickness (mm) of a CPU and the width will automatically d
efault to"
3535 PRINT ".1 mm such that a rail of width 1.7 mm can be modeled as 17 CPU's."
3540 PRINT
3545 PRINT " For your convenience the thermal conductivities (watts/M-C) of t
hree alloys"
3550 PRINT "commonly used as material for conduction rails are given below:",LIN
(1)
3555 PRINT "Al 5052= 138.2 W/M-C ..... AL 6101= 215.7 W/M-C ..... Cu 113 = 389
.8 W/M-C"
3560 PRINT
3565 O1de=0
3570 Ans#="1"
3575 INPUT "ENTER THE THICKNESS OF THE THERMAL CONDUCTION PATHS or CPU's (mm)",A
ns#
3580 IF Ans#="BACK_UP" THEN Leads
3585 T1=ABS(VAL(Ans#))
3590 PRINT "THICKNESS OF CPU's = ";T1;"mm"
3595 Ans#="1"
3600 ! INPUT "ENTER THE WIDTH OF THE CPU's (mm)",Ans#
3605 IF Ans#="BACK_UP" THEN 3570
3610 W1=ABS(VAL(Ans#))
3615 A1=-W1*T1 !##### NOTE THAT THIS AREA IS NEGATIVE FOR CPU's
3620 PRINT "WIDTH OF CPU's = ";W1;"mm AREA FOR HEAT TRANSFER PER CPU = "
;A1;"mm^2"
3625 Ans#="138.2"
3630 INPUT "ENTER THE THERMAL CONDUCTIVITY OF THE CONDUCTION PATHS (W/M-C)",Ans#
3635 IF Ans#="BACK_UP" THEN 3570
3640 K1=ABS(VAL(Ans#))
3645 PRINT "THERMAL CONDUCTIVITY = ";K1;"Watts/M-Deg C"
3650 WAIT 1500
3655 GOTO Leads_enter ! END OF CPU
3660 !
3665 Leads_size:3#="NUMBER OF LEADS"
3670 GOSUB Pagehead
3675 A1#="LEADS"
3680 PRINT " This section of the program allows the entry of the size and con
ductivity of"

```


BOARDS .. DATA INPUT FOR THERMELEM

```

3685 PRINT "Leads (traces) on the surface of the circuit board. These act as both"
3690 PRINT "electrical and thermal conductors between the regions. When entering the width"
3695 PRINT "figure an average width for all the leads."
3700 PRINT LIN(1)," The thermal conductivity will default to pure copper (384 Watts/M-Deg C)"
3705 PRINT "with no entry."
3710 Old=0
3715 Ans$="0.033"
3720 INPUT "ENTER THE THICKNESS OF THE LEADS (TRACES) ON THE CIRCUIT BOARD (mm)",Ans$
3725 IF Ans$="BACK_UP" THEN Leads
3730 T1=ABS(VAL(Ans$))
3735 PRINT LIN(1),"LEAD THICKNESS      =";T1;"mm"
3740 Ans$="1"
3745 INPUT "ENTER THE AVERAGE WIDTH OF THE LEADS (TRACES) ON THE CIRCUIT BOARD (mm)",Ans$
3750 IF Ans$="BACK_UP" THEN 3715
3755 W1=ABS(VAL(Ans$))
3760 A1=W1*T1
3765 PRINT "AVG WIDTH OF LEADS  = ";W1;"mm      AREA FOR HEAT TRANSFER PER LEAD"
3770 A1;"mm^2"
3775 Ans$="384"
3775 INPUT "ENTER THE CONDUCTIVITY OF THE TRACES (DEFAULT COPPER = 384Watts/M-degk)",Ans$
3780 K1=ABS(VAL(Ans$))
3785 PRINT "CONDUCTIVITY OF THE LEADS =";K1;" Watts-M-C"
3790 WAIT 1500
3795 Leads_enter: 3$="NUMBERS OF ";A1$;" BETWEEN REGIONS"
3800 GOSUB Pagehead
3805 PRINT "      This section of the program allows the entry of the number of the ";A1$
3810 PRINT "that cross each of the internal region boundaries. If these are on both sides"
3815 PRINT "of the board add both numbers together. The flashing cross will move to the"
3820 PRINT "appropriate location on the screen but the graphics picture will not remain."
3825 PRINT "If a hard copy of the graphics is needed for a guide, recall that k3 will"
3830 PRINT "provide one. The picture will return to the screen while the number of ";A1$
3835 PRINT "is labeled and the flashing cursor will move to the next location to be entered."
3840 PRINT LIN(1),"DO NOT USE k0 (BACK_UP) WHILE THE NUMBERS OF ";A1$;" ARE BEING ENTERED!"
3845 PRINT LIN(1),"There will be correction opportunities later."
3850 DISP "PRESS CONT WHEN READY TO START WITH REGION #1"
3855 FAUSE
3860 GOTO Leads_in
3865 Leads_label: 1 HERE THE NUMBERS OF LEADS OR CPU'S IS WRITTEN ON THE SCREEN
3870 CSIZE 2.5
3875 GRAPHICS
3880 LABEL USING "K";N1
3885 PEN -1
3890 LDIR -PI
3895 LABEL USING "K";N1

```


BOARDS .. DATA INPUT FOR THERMELE..

```

3900 PEN 1
3905 LDIR 0
3910 IF Old=<>PI THEN WAIT 500
3915 RETURN
3920 Leads_old:CSIZE 2.5
3925 S$="NUMBERS OF LEADS"
3930 A1$="LEADS"
3935 IF A1<0 THEN A1$="CPU's"
3940 GOSUB Pagehead
3945 PRINT "      This section of the program displays the numbers of leads crossi
ng "
3950 PRINT "boundaries of regions by placing numbers on the sides of the regions
that"
3955 PRINT "represent the informations stored in ";Name$;". You will be allowed
to make"
3960 PRINT "connections to that information and re-store in on mass storage if r
equired."
3965 PRINT
3970 ! PRINT "If you do not desire to view the data concerning number of leads,
enter any "
3975 ! PRINT "number before you press CONT ."
3980 DISP "PRESS CONT WHEN READY TO VIEW DATA "
3985 Leads_in: FOR I=1 TO Nneg
3990 J=1 ! HERE IS BOTTOM OF THE REGION
3995 GRAPHICS
4000 IF I+Nxr<=Nneg THEN 4025
4005 N1(J,I)=N1=0 ! HERE IS BOTTOM OF THE BOARD WHERE CONNECTORS WILL GO
4010 MOVE X(I),Y(I)-.45+Hr
4015 GOSUB Leads_label
4020 GOTO 4185
4025 IF (Itype(I)<>10) OR (Itype(I+Nxr)<>10) THEN 4100
4030 MOVE X(I)+.32-Lr,Y(I)-.45+Hr
4035 IF Old=<>PI THEN 4050
4040 N1=N1(J,I)
4045 GOTO 4080
4050 POINTER X(I)+.32-Lr,Y(I)-.45+Hr,2
4055 WAIT 2000
4060 DISP "ENTER THE NUMBER OF ";A1$;" BETWEEN REGIONS ";CHR$(132);I;CHR$(128)
;" AND ";CHR$(132);I+Nxr;CHR$(128);
4065 INPUT N1
4070 N1=ABS(N1)
4075 N1(J+2,I+Nxr)=N1(J,I)=N1
4080 GOSUB Leads_label
4085 MOVE X(I+Nxr)+.32-Lr,Y(I+Nxr)+.42+Hr
4090 GOSUB Leads_label
4095 GOTO 4185
4100 MOVE X(I),Y(I)-.45+Hr
4105 IF Old=<>PI THEN 4120
4110 N1=N1(J,I)
4115 GOTO 4150
4120 POINTER X(I),Y(I)-.45+Hr,2
4125 WAIT 2000
4130 DISP "ENTER THE NUMBER OF ";A1$;" BETWEEN REGIONS ";CHR$(132);I;CHR$(128)
;" AND ";CHR$(132);I+Nxr;CHR$(128);
4135 INPUT N1
4140 N1=ABS(N1)
4145 N1(J,I)=N1(J+2,I+Nxr)=N1
4150 GOSUB Leads_label

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BOARDS .. DATA INPUT FOR THERMELEN

```

4155 MOVE X(I+Nxr),Y(I+Nxr)+.42+Hr
4160 GOSUB Leads_label
4165 J=2 ! HERE IS FOR RIGHT SIDE OF REGION
4170 IF I MOD Nxr<>0 THEN 4195
4175 N1(I)=N1=0 ! HERE IS THE RIGHT SIDE OF THE BOARD
4180 MOVE X(I)+.42+Lr,Y(I)
4195 GOSUB Leads_label
4190 GOTO 4340
4195 IF (Itype(I)<>9) OR (Itype(I+1)<>9) THEN 4270
4200 MOVE X(I)+.42+Lr,Y(I)-.32+Hr
4205 IF Oldc<>PI THEN 4220
4210 N1=N1(J,I)
4215 GOTO 4250
4220 POINTER X(I)+.42+Lr,Y(I)-.32+Hr,2
4225 WAIT 2000
4230 DISP "ENTER THE NUMBER OF ";A1$;" BETWEEN REGIONS ";CHR$(132);I;CHR$(128)
;" AND ";CHR$(132);I+1;CHR$(128);
4235 INPUT N1
4240 N1=ABS(N1)
4245 N1(J,I)=N1(J+2,I+1)=N1
4250 GOSUB Leads_label
4255 MOVE X(I+1)+.42+Lr,Y(I+1)-.32+Hr
4260 GOSUB Leads_label
4265 GOTO 4335
4270 MOVE X(I)+.42+Lr,Y(I)
4275 IF Oldc<>PI THEN 4290
4280 N1=N1(J,I)
4285 GOTO 4315
4290 POINTER X(I)+.42+Lr,Y(I),2
4295 WAIT 2000
4300 DISP "ENTER THE NUMBER OF ";A1$;" BETWEEN REGIONS ";CHR$(132);I;CHR$(128)
;" AND ";CHR$(132);I+1;CHR$(128);
4305 INPUT N1
4310 N1=ABS(N1)
4315 GOSUB Leads_label
4320 N1(J+2,I+1)=N1(J,I)=N1
4325 MOVE X(I+1)+.42+Lr,Y(I)
4330 GOSUB Leads_label
4335 J=3 ! HERE IS FOR TOPS OF EACH REGION
4340 IF I>Nxr THEN 4360
4345 N1(J,I)=N1=0
4350 MOVE X(I),Y(I)+.42+Hr
4355 GOSUB Leads_label
4360 J=4 ! HERE IS FOR LEFT SIDE OF REGION OR BOARD
4365 IF (I-1) MOD Nxr=0 THEN 4375
4370 GOTO 4390
4375 N1(J,I)=N1=0
4380 MOVE X(I)-.42+Lr,Y(I)
4385 GOSUB Leads_label
4390 NEXT I
4395 GRAPHICS
4400 MOVE 160,130
4405 LOOP 6
4410 CSIZE 3
4415 LABEL USING "k";" OF "A1$
4420 DRAW X(Nxr),Y(Nxr)+Hr/2
4425 POINTER 0,0,0
4430 WAIT 5000

```


BOARDS .. DATA INPUT FOR THERMELEX

```

4435 EXIT GRAPHICS
4440 RETURN
4445 Leads_chae: GOSUB Error
4450 Leads_chai: S$="CORRECTIONS TO NUMBER OF ";A1$;
4455 ON ERROR GOTO Leads_chae
4460 Check=0
4465 GOSUB Pagehead
4470 PRINT "    You may now make corrections to the numbers of ";A1$; " crossing
the boundaries."
4475 PRINT "Recall that k3 will provide a hard copy of the graphics if needed
while k2 "
4480 PRINT "will return the graphics picture to the screen for visual checking.
"
4485 PRINT
4490 PRINT "In response to the prompts below, INPUT Reg #, Reg #, CORRECT # OF
";A1$;LINK(1)
4495 PRINT "IF THERE ARE NO CHANGES PRESS CONT KEY WITH NO INPUT."
4500 LOG 5
4505 IF Check>0 THEN BEEP
4510 IF Check=0 THEN PRINT LINK(3),"CHECK OVER THE FIGURE, YOU HAVE MADE AN IL
LOGICAL CHOICE OF REGIONS."
4515 Check=Check+1
4520 Reg1=0
4525 DISP "REG # 1 REG # 1 CORRECT # OF ";A1$;
4530 INPUT Reg1,Reg2,Newn1
4535 IF Reg1=0 THEN RETURN
4540 IF (Reg1>Nreg) OR (Reg2>Nreg) THEN 4465
4545 IF Reg2<Reg1 THEN 4565
4550 Dum=Reg2
4555 Reg2=Reg1
4560 Reg1=Dum
4565 J=0
4570 IF (Reg1+1=Reg2) AND (Reg1 MOD Nxr<>0) THEN J=2
4575 IF Reg1+Nxr=Reg2 THEN J=1
4580 IF J<>0 THEN 4555
4585 EXIT GRAPHICS
4590 S$="ERROR IN CORRECTIONS"
4595 GOSUB Pagehead
4600 PRINT LINK(5),SPACE(5), " THOSE TWO REGIONS DO NOT CONNECT TRY AGAIN"
4605 BEEP
4610 WAIT 2500
4615 GOTO Leads_cha
4620 ! HERE IS THE CORRECTION SCHEME
4625 Leads_erase: PEN -1
4630 GOSUB Leads_label
4635 N1=Newn1
4640 PEN 1
4645 GOSUB Leads_label
4650 RETURN
4655 IF J=2 THEN 4745
4660 IF (Itype(Reg1)<>10) OR (Itype(Reg2)<>10) THEN 4705
4665 MOVE X(Reg1)+.32*Lr,Y(Reg1)-.45*Hr
4670 N1=N1(J,Reg1)
4675 GOSUB Leads_erase
4680 MOVE X(Reg2)+.32*Lr,Y(Reg2)+.42*Hr
4685 N1=N1(J+2,Reg2)
4690 GOSUB Leads_erase
4695 N1(1,Reg1)=N1(1,Reg2)=Newn1

```


BOARDS .. DATA INPUT FOR THERMELEN

```

4700 GOTO Leads_change
4705 MOVE X(Reg1),Y(Reg1)+.45*Hr
4710 N1=N1(J,Reg1)
4715 GOSUB Leads_erase
4720 MOVE X(Reg2),Y(Reg2)+.42*Hr
4725 N1=N1(J+2,Reg2)
4730 GOSUB Leads_erase
4735 N1(J,Reg1)=N1(J+2,Reg2)=Newn1
4740 GOTO Leads_cha
4745 ! HERE WE ARE TO CORRECT THE RIGHT SIDE OF REGIONS
4750 IF (Itype(Reg1)<>9) OR (Itype(Reg2)<>9) THEN 4795
4755 MOVE X(Reg1)+.42*Ln,Y(Reg1)+.32*Hr
4760 N1=N1(J,Reg1)
4765 GOSUB Leads_erase
4770 MOVE X(Reg2)+.42*Ln,Y(Reg2)+.32*Hr
4775 N1=N1(J+2,Reg2)
4780 GOSUB Leads_erase
4785 N1(J,Reg1)=N1(J+2,Reg2)=Newn1
4790 GOTO Leads_change
4795 MOVE X(Reg1)+.42*Ln,Y(Reg1)
4800 N1=N1(J,Reg1)
4805 GOSUB Leads_erase
4810 MOVE X(Reg2)+.42*Ln,Y(Reg2)
4815 N1=N1(J+2,Reg2)
4820 GOSUB Leads_erase
4825 N1(J,Reg1)=N1(J+2,Reg2)=Newn1
4830 GOTO Leads_cha
4835 Tempin: ! THIS SECTION INPUTS THE KNOWN TEMPERATURES OR POWERS OF ELEMENTS
4840 EXIT GRAPHICS
4845 S$="TEMPERATURES OR POWER LEVELS OF COMPONENTS"
4850 GOSUB Pagehead
4855 PRINT " The thermal model used by this program assumes each component to
be a heat"
4860 PRINT "source for which the user specifies either the maximum junction temp
erature or"
4865 PRINT "the rate of heat generation within that component. When the maximum
junction"
4870 PRINT "temperature is specified, the maximum steady state power levels are
calculated."
4875 PRINT "When the rate of power dissipation is specified, the steady state jun
ction"
4880 PRINT "temperatures are calculated."
4885 PRINT
4890 PRINT "The program uses the component surface temperature in the thermal mo
del and "
4895 PRINT "therefore requires a case to junction thermal resistance (RJ_c); how
ever,"
4900 PRINT "if zero is specified then the surface temperature is assumed to be t
he same as"
4905 PRINT "the junction temperature. When components span two regions, enter h
alf the "
4910 PRINT "component power for each region."
4915 PRINT LIN(1)," All entries must be in Deg C or Watts and deg C/Watts."
4920 IF Old<>PI THEN 4945
4925 DISP "PRESS CONT WHEN READY TO VIEW THE DATA FROM ";CHR$(132);Name$;CHR$(
128);" FOR POSSIBLE CHANGES"
4930 PAUSE
4935 GOTO Temp_cha

```


BOARDS .. DATA INPUT FOR THERMELEX

```

4940 !
4945 Ans$="1"
4950 MAT Pow=ZER
4955 MAT Tj=ZER
4960 MAT Rj_c=ZER
4965 INPUT "DO YOU DESIRE TO SPECIFY POWER LEVELS (1) OR TEMPS (2) ?",Ans$
4970 IF Ans$="BACK_UP" THEN RETURN
4975 Ans=VAL(Ans$)
4980 IF (Ans=1) OR (Ans=2) THEN 4995
4985 GOSUB Errin
4990 GOTO Tempin
4995 IF Ans=1 THEN Pow_in
5000 Temp_in: Tem_sol=0 ! HERE INPUT TEMPERATURES WILL SOLVE FOR POWERS LATER
5005 S$="INPUT OF JUNCTION TEMPERATURES"
5010 GOSUB Pagehead
5015 PRINT " You are now entering junction temperatures (deg C) and junction
to case"
5020 PRINT "thermal resistance (deg C/Watt). Do not use k0 (Back_up) option w
hile entering"
5025 PRINT "the data."
5030 PRINT LIN(3)
5035 PRINT " I Tj(I) Rj_c(I) "
5040 FOR I=1 TO Nreg
5045 IF Itype(I)=0 THEN 5060
5050 DISP "FOR ELEMENT IN REGION";I;"ENTER Tjunc,Rj_c";
5055 INPUT Tj(I),Rj_c(I)
5060 PRINT SPA(1),I,Tj(I),Rj_c(I)
5065 Tj(I)=Tj(I)+273
5070 NEXT I
5075 GOTO Temp_cha ! END OF TEMP_IN
5080 Pow_in: Tem_sol=1 ! HERE INPUT POWER LEVELS WILL SOLVE FOR TEMPERATURES
5085 S$="INPUT OF COMPONENT POWER LEVELS"
5090 GOSUB Pagehead
5095 PRINT " You are now entering component power dissipation (Watt) and jun
ction to"
5100 PRINT "case thermal resistances (deg C/Watt). Do not use k0 (Back_up whi
le entering"
5105 PRINT "the data."
5110 PRINT LIN(3)
5115 PRINT " I Pow(I) Rj_c(I) "
5120 FOR I=1 TO Nreg
5125 IF Itype(I)=0 THEN 5140
5130 DISP "FOR ELEMENT IN REGION #";I;"ENTER Pow(I),Rj_c(I)";
5135 INPUT Pow(I),Rj_c(I)
5140 PRINT SPA(1),I,Pow(I),Rj_c(I)
5145 Tj(I)=273
5150 NEXT I
5155 GOTO Temp_cha ! END OF POW_IN
5160 !
5165 Temp_cha: GOSUB Error
5170 Temp_cha: THIS SECTION ALLOWS CHANGES TO THE TEMPS OR POWER LEVELS
5175 S$="DATA FOR " & Pict1b1s
5180 GOSUB Pagehead
5185 PRINT " The data listed below are the current values for the variables
specified."
5190 PRINT "REGION # Tjunc (DegC) Power (Watts) Rcase-j(W/C) "
5195 FOR I=1 TO Nreg
5200 PRINT TAB(2),I,TAB(17),Tj(I)-273,TAB(33),Pow(I),TAB(48),Rj_c(I)

```


BOARDS ... DATA INPUT FOR THERMELEX

```

5205      NEXT I
5210 PRINT LIN(2)
5215 IF Skip=PI THEN GOTO 5360
5220 PRINT "Use the DISPLAY up-arrow OR down-arrow to move the data list as requi
ired"
5225 Check=0
5230 Ans$="0"
5235 INPUT "ANY CHANGES ? INPUT REG # IF YES OR PRESS CONT FOR NO CHANGES",Ans
$
5240 IF Ans$="BACK UP" THEN Tempin
5245 Reg1=INT(VAL(Ans$))
5250 IF (Reg1)-1 AND (Reg1+Nreg+1) THEN 5265
5255 GOSUB Errin
5260 GOTO 5230
5265 IF (Reg1=0) AND (Check=0) THEN Hand
5270 IF (Reg1=0) AND (Check<0) THEN Temp_cha
5275 DISP "TO CHANGE VALUES IN REGION #";Reg1;
5280 Check=1
5285 IF Tem_sol=1 THEN DISP "ENTER Power , Pj_c";
5290 IF Tem_sol=0 THEN DISP "ENTER Tjunc , Pj_c";
5295 IF Tem_sol=1 THEN INPUT Pow(Reg1),Rj_c(Reg1)
5300 IF Tem_sol=0 THEN INPUT Tj(Reg1),Rj_c(Reg1)
5305 IF Tem_sol=0 THEN Tj(Reg1)=Tj(Reg1)+273
5310 PRINT LIN(1),TAB(2),Reg1;TAB(17),Tj(Reg1)-273;TAB(33),Pow(Reg1);TAB(48),Pj
_c(Reg1);" *** CHANGE ***"
5315      GOTO 5230
5320 Hand: ! THIS SECTION PRINTS A COPY OF THE INPUT DATA IF REQUESTED
5325 Ans$="N"
5330 INPUT "DO YOU DESIRE A PRINTED COPY OF THE DATA ABOVE (N or Y)",Ans$
5335 IF Ans$="BACK UP" THEN Temp_cha
5340 IF Ans$="N" THEN RETURN
5345 PRINTER IS 0
5350 Skip=PI
5355 GOTO 5190
5360 PRINT TAB(39-LEN:"THE ABOVE DATA IS FOR "%Pict1b1$>2),"THE ABOVE DATA IS F
OR "%Pict1b1$,LIN(1)
5365 PRINT "BOARD LENGTH (defined along air flow)="+Bd1;"mm" HEIGHT ="
Bdh;"mm",LIN(1)
5370 PRINT "BOARD THICKNESS="+Thick_b;"mm" CONDUCTIVITY ="
Kb;"Watts/M-K",LIN(2)
5375 PRINT "THE BOARD MOIEL ASSUMES ";A1$;" AS CONDUCTION PATHS WITH AN AREA OF
";ABS(A1);" mm^2",LIN(1)
5380 PRINT "THERMAL CONDUCTIVITY OF THE ";A1$;" ="K1;" Watts/M-C"
5385 PRINT "
",LIN(2)


---


5390 PRINTER IS 16
5395 RETURN
5400 !
5405 Stowe: GOSUB Erron
5410 Stow: ! THIS SECTION PLACES THE DESCRIPTION OF THE CIRCUIT BOARD ON TAPE
5415 ON ERPR GOTO Stowe
5420 S$="RECORD BOARD DESCRIPTION ON MASS STORAGE"
5425 GOSUB Pagehead
5430 PRINT " You may record all the data concerning the circuit board on any
available"
5435 PRINT "mass storage device. This allows any user to retrieve the descripti
on at some"
5440 PRINT "later time without the need to input all the details. This option o
ccurs both"

```


BOARDS .. DATA INPUT FOR THERMELEN

```

5445 PRINT "before and after the thermal analysis. Enter desired data file na
me below,"
5450 PRINT "be sure to include the mass storage unit specifier if not the default
t."
5455 PRINT "For example      :T14 , :F8 , Y12 etc."
5460 Ans$="Y"
5465 INPUT "DO YOU DESIRE TO RECORD THE DESCRIPTION DATA (Y or N)?",Ans$
5470 IF Ans$="BACK UP" THEN RETURN
5480 IF UPC$(Ans$(I,1))="N" THEN RETURN
5485 IF Oldc<>PI THEN 5505
5490 PRINT LIN(5),"THE PRESENT DESCRIPTIVE TITLE FOR THAT BOARD IS ";CHR$(132);P
ict1b1$;CHR$(128)
5495 EDIT "CHANGE THE TITLE OR PRESS CONT WITH NO ENTRY FOR NO CHANGE.",Pic1b
1$
5500 IF Pict1b1$="BACK UP" THEN Stop
5505 Ans$=Name$
5510 EDIT "UNDER WHAT NAME DO YOU DESIRE TO STORE THE DATA (change below)?",Name
$
5515 IF Name$="BACK UP" THEN 5490
5520 IF Name$=Ans$ THEN 5560
5525 Ans$="Y"
5530 DISP "DOES A DATA FILE WITH AT LEAST";40+Nneg+600;" BYTES EXIST UNDER THAT
NAME (Y or N)?":
5535 INPUT Ans$
5540 IF Ans$="BACK UP" THEN 5505
5545 IF UPC$(Ans$(I,1))="Y" THEN 5560
5550 DISP "WORKING CREATING DATA FILE FOR ";Name$;" THAT IS";40+Nneg+600;"BYTE
S IN SIZE"
5555 CREATE Name$,1,40+Nneg+600
5560 ASSIGN #5 TO Name$
5565 PRINT LIN(3),"WORKING WRITING BOARD DESCRIPTION OF ";Pict1b1$;" ON MASS S
TORAGE"
5570 DISP
5575 READ #5,1
5580 PRINT #5;Name$,Pict1b1$,Case$,Bdl,Bdh,Sca,Nnr,Nyr,Nneg,Thick_b,Kb,Al,Kl,Tem
sol
5585 FOR I=1 TO Nneg
5590 PRINT #5;I;type(I),X(I),Y(I),Tj(I),Pow(I),Rj_c(I)
5595 FOR J=1 TO 4
5600 PRINT #5;H1(J,I)
5605 NEXT J
5610 NEXT I
5615 PRINT #5;END
5620 ASSIGN #5 TO +
5625 PRINTER IS 0
5630 PRINT LIN(2),"THE CIRCUIT LISTED BELOW IS STORED UNDER THE FILE NAME ";CHR$
(132);Name$;CHR$(128)
5635 PRINT LIN(2),SPA(25),Pict1b1$,LIN(2)
5640 PRINT SPA(25),"SAVE FOR YOUR RECORDS"
5645 PRINT "
",LIN(2)
5650 PRINTER IS 16
5655 DISP
5660 RETURN
5665 Error:1
5670 BEEP
5675 WAIT 300
5680 IF ERRN=56 THEN Err_name

```



```

5685 PRINT LIN(20),SPAC(10),"ERROR NUMBER";ERRN;"HAS OCCURRED IN LINE";ERPL;". PR
ESS CONT WHEN READY"
5690 DISP
5695 BEEP
5700 PAUSE
5705 RETURN
5710 !
5715 Err_name:!! THIS SECTION FOR IMPROPER FILE NAME
5720 PRINTER IS 16
5725 PRINT PAGE
5730 Msus$="DEFAULT MASS STORAGE"
5735 FOR I=2 TO LEN(Name$)
5740 IF Name$(I,I)=":" THEN 5755
5745 NEXT I
5750 GOTO 5770
5755 Msus$=Name$(I)
5760 CAT Msus$
5765 GOTO 5775
5770 CAT
5775 PRINT LIN(2),CHR$(132);Name$(1,I-1);CHR$(128);" is NOT on ";Msus$;" with th
at spelling....."
5780 PRINT LIN(1),"CHECK OVER THE DIRECTORY ABOVE FOR CORRECT NAME....."
."
5785 DISP "PRESS CONT WHEN READY"
5790 PAUSE
5795 RETURN

```


APPENDIX D

```

10 | THERML .....THERMAL ANALYSIS PROGRAM FOR .....
20 |
30 |
40 | ***** THERMELEX *****
50 |
60 | A SYSTEM OF PROGRAMS FOR THE HP 9845
70 |
80 | TO PERFORM THERMAL ANALYSIS OF ELECTRONIC CIRCUIT BOARDS
90 |
100 | -----
110 | *
120 | *
130 | * PREPARED AT THE NAVAL POSTGRADUATE SCHOOL MONTEREY, CA *
140 | *
150 | * R. A. FOLTZ LCDR USN *
160 | *
170 | * ||||| THERML ||||| ..... JUNE 1980 *
180 | * -----
190 |
200 | OPTION BASE 1
210 | PRINTER IS 15
220 | DIM Str$(701),Type$(0:14),Name$(221),Y1b1$(0:251)
230 | COM Map,Name$,Pic1b1$(501),Case$(501),Bd1,Bch,Scs,Thick_b,Tem_sol,Kb,A1,K1
240 | COM SHORT X(50),Y(50),Tj(50),Pow(50),Pj_c(50)
250 | COM INTEGER Imap(50),N1(4,50),Nar,Nyr,Nreg
260 | INTEGER Npic(15)
270 | SHORT Re(50),Re_condu(50),Re_conv(50),Rtot_b(50),Rtot_r(50),R1(4,50),Rel(5
0),Rb_condu(50)
280 | SHORT Wideset(14),Lenset(14)
290 | SHORT Le(50),Hex(50),Hex(50),Tex(50),Tair(50),A(50,50),B(50),Tb(50)
300 | Map=INT(Map)
310 | IF (Map=0) OR (Map>3) THEN Oldpict
320 | Start_over: ON Map GOTO Oldpict,Thermal,Thermal
330 | GOTO Oldpict
340 | Oldpict: GOSUB Error
350 | Oldpict: ! THIS SECTION RETRIEVES A BOARD DESCRIPTION OFF A MASS STORAGE DEV
ICE FOR THE PURPOSE OF DEBUGGING THERMAL
360 | ON ERROR GOTO Oldpict
370 | Old=PI
380 | St="BOARD DESCRIPTION FROM MASS STORAGE DEVICE"
390 | GOSUB Pagehead
400 | PRINT " You have chosen to input the circuit board description in THERM
L directly"
410 | PRINT "from a mass storage device. This program in the THERMELEX System wi
ll NOT "
420 | PRINT "allow graphical data checking and while faster, there is the chances
that the"
430 | PRINT "data is incorrect. If you decide that it would be better to check t
he data"
440 | PRINT "press K0 (Back_up) and BOARDS will be loaded from the DEFAULT ma
ss storage unit."
450 | PRINT
460 | PRINT " The data file containing the board description must have been st
ored by "
470 | PRINT "this program. Enter the data file name below, be sure to include th
e mass "
480 | PRINT "storage unit specifier if needed.(eg :T14,:F8,:Y12 etc)"
490 | PRINT LIN(1)," Do NOT use quotes"

```


THERMAL .. THERMAL ANALYSIS FOR THERMELEN

```

500 EDIT "UNDER WHAT FILE NAME IS THE CIRCUIT BOARD FILED (change or enter below)",Name$
510 IF Name$="BACK_UP" THEN 530
520 GOTO 550
530 Map=1
540 LOAD "BOARDS",1
550 ASSIGN #1 TO Name$
560 READ #1,1
570 READ #1;Name$,Pict1b1$,Case$,Bd1,Bdh,Sca,N,nr,Nyn,Nneg,Thick_b,Kb,Al,K1,Tem_
sol
580 FOR I=1 TO Nneg
590 READ #1;Itype$,I,X(I),Y(I),Tj(I),Pow(I),Rj_c(I)
600 FOR J=1 TO 4
610 READ #1;N1(J,I)
620 NEXT J
630 NEXT I
640 !
650 GOTO Thermal
660 Thermal: GOSUB Error
670 Thermal: ! THIS SECTION IS THE MAIN INPUT AND CALLING ROUTINE
680 ON ERROR GOTO Thermal$
690 S$="THERMAL ANALYSIS OF"
700 GOSUB Pagehead
710 PRINT TAB(37-LEN(Pict1b1$)-2);CHR$(133);Pict1b1$;CHR$(128);LIN(2)
720 PRINT " This section assumes you have completely and correctly described
the board"
730 PRINT "itself. You will be asked questions concerning ONLY the environment
."
740 PRINT " The first questions are concerned with the cooling air supply.
Recall the"
750 PRINT "direction of air flow on the graphics picture is assumed to be left
to right."
760 PRINT "The clearance between the boards is used to determine the velocity o
f the "
770 PRINT "cooling air.",LIN(2)
780 Ans$="20"
790 Map=0
800 INPUT "ENTER THE INLET TEMPERATURE OF THE COOLING AIR (deg C)",Ans$
810 IF Ans$="BACK_UP" THEN Start_over
820 Tair=VAL(Ans$)
830 PRINT " INLET AIR TEMP Tair=";Tair;"deg C"
840 Tair=Tair+273 ! ALL CALCULATIONS DONE IN ABSOLUTE TEMP
850 Ans$=".0005"
860 INPUT "ENTER THE AIR SUPPLY PER BOARD (M3/SEC)",Ans$
870 IF Ans$="BACK_UP" THEN Thermal
880 Fair=VAL(Ans$)
890 PRINT " FLOW RATE OF AIR=";Fair;"M3/Sec"
900 Ans$="15.24"
910 INPUT "ENTER THE DISTANCE FROM THE FACE OF THE BOARD TO THE NEXT OBJECT (mm
)",Ans$
920 IF Ans$="BACK_UP" THEN 780
930 Zb=VAL(Ans$)
940 PRINT " BOARD SPACING=";Zb;"mm"
950 Zb=Zb+.001
960 Ans$="NULL"
970 INPUT "ALL OK?..PRESS CONT ANY ENTRY FOLLOWED BY CONT WILL ALLOW REENTR
Y OF ALL",Ans$
980 IF Ans$="NULL" THEN 1000

```


THERML .. THERMAL ANALYSIS FOR THERMELEN

```

990 GOTO Thermal
1000 S$="CONVERGENCE CRITERIA"
1010 GOSUB Pagehead
1020 PRINT "    Convergence is indicated by successive iterations that result in
element"
1030 PRINT "temperatures that differ only by some small amount. Each element te
perature"
1040 PRINT "is compared to that obtained in the previous iteration and if the l
argest"
1050 PRINT "difference is less than a maximum specified error, results are print
ed."
1060 PRINT
1070 PRINT "    Typically two or three iterations result in a maximum difference
on the"
1080 PRINT "order of one degree centigrade when solving for temperatures and fou
r or five"
1090 PRINT "iterations will result in a maximum difference on the order of .1 W
att when "
1100 PRINT "solving for powers."
1110 IF Tem_sol=1 THEN Ans$=".5"
1120 IF Tem_sol=0 THEN Ans$="1"
1130 IF Tem_sol=1 THEN INPUT "ENTER THE MAXIMUM DIFFERENCE BETWEEN ITERATIONS (
deg C) DEFAULT=.5",Ans$
1140 IF Tem_sol=0 THEN INPUT "ENTER THE MAXIMUM PERCENT CHANGE BETWEEN ITERATIO
NS (Watt) DEFAULT=1%",Ans$
1150 IF Ans$="BACK_UP" THEN Thermal
1160 Errmax=ABS(VAL(Ans$))
1170 GOSUB Database ! THE FOLLOWING LINES FORM THE MAIN CALLING ROUTINE
1180 GOSUB Calc0
1190 GOSUB Calc1
1200 GOSUB Calc_air
1210 GOSUB Calc_t
1220 GOSUB Calc2
1230 GOSUB Debug
1240 GOSUB Solve
1250 GOSUB Units
1260 IF Bomb=1 THEN 1280
1270 GOSUB Output
1280 GOSUB What_now
1290 IF Map=0 THEN GOTO Thermal
1300 GOTO Oldpict
1310 !
1320 ! END OF THE MAIN CONTROL SECTION OF THE PROGRAM THERML
1330 !
1340
1350 Database: ! *****DATABASE*****
1360 ! ARE READ IN FROM THE DATA LINES BELOW
1370 DISP "WORKING ON NON-CHANGING PARAMETERS"
1380 PRINT PAGE
1390 Apxin=4.3E-7 !X-SECTIONAL AREA FOR PINS (M^2)
1400 Aspin=1E-5 !SURFACE AREA FOR PINS (M^2)
1410 Beta=3.33E-3 !VOL COEFF OF ENPA. AIR (1/deg K) AT 300 deg K
1420 Cpa=1.006E3 !SPECIFIC HEAT OF AIR (WATT-SEC/Kg-deg K)
1430 Dis=.001 !AVG DISTANCE FROM BOTTOM OF DIP TO BOARD
1440 Epsb=.3 !EMISSIVITY OF THE SURFACE OF BOARD
1450 Eps=.9 !EMISSIVITY OF THE DIP SURFACE
1460 G=9.81 !GRAVITY (M/Sec^2)
1470 Gnu=1.684E-5 !KINEMATIC VISCOSITY AIR (M^2/Sec)

```


THERML .. THERMAL ANALYSIS FOR THERMELEX

```

1480 Hec=.003          !HEIGHT OF CERAMIC DIP PACKAGE ++++++||| check
1490 Hep=.005          !HEIGHT OF PLASTIC DIP PACKAGE ++++++||| CHECK
1500 Ks=59             !THERMAL COND OF STEEL (WATTS/M-deg K)
1510 Kair=.026         !THERMAL COND OF AIR (WATTS/M-deg K) 300 deg K
1520 Kpin=384          !THERMAL COND OF PINS (WATTS/M-deg K)
1530 Lpin=.0025        !AVG LENGHT OF PINS (M)
1540 Mu=1.993E-5       !DYNAMIC VISCOSITY 300 K (Kg/M-sec)
1550 Pr=.703           !PRANDTL NUMBER (AT 300deg K)
1560 Rho=1.1774        !DENSITY OF AIR AT 300 K (Kg/M^3)
1570 Sig=5.67E-8       !STEFFAN-BOLTZMAN (W/M^2-deg K^4)
1580 Itt=0
1590 RESTORE 1630
1600 FOR I=1 TO 14      ! THIS READS THE CASE WIDTHS FOR EACH TYPE
1610 READ Wideset(I)
1620 NEXT I
1630 DATA .25,.725,.25,.825,.55,1.25,0,0,.6,1,.18,.35,.48,.72 ! ALL IN INCHES
1640 FOR I=1 TO 14      ! THIS READS THE CASE LENGTHS FOR EACH TYPE
1650 READ Lsetet(I)
1660 NEXT I
1670 DATA .725,.25,.825,.25,1,.55,0,0,1,.6,.18,.35,.48,.72 ! ALL IN INCHES
1680 MAT Wideset=(25.4)*Wideset ! CONVERT TO mm
1690 MAT Lsetet=(25.4)*Lsetet
1700 FOR I=1 TO 14      ! THIS READS THE # OF PINS FOR EACH TYPE
1710 READ Npin(I)
1720 NEXT I
1730 DATA 14,14,16,16,24,24,0,0,20,20,16,24,40,64
1740 FOR I=0 TO 14      ! THIS READS THE CASE LABELS FOR EACH TYPE
1750 READ Typeet(I)
1760 NEXT I
1770 DATA EMPTY,DIP 14,DIP 14,DIP 16,DIP 16,DIP 24,DIP 24,NULL,NULL,DIP 40,DIP 4
0,FLAT16,FLAT24,FLAT40,FLAT64
1780 FOR I=1 TO Nreg
1790 IF Itype(I)=0 THEN 1830
1800 Le(I)=Lsetet(Itype(I))
1810 We(I)=Wideset(Itype(I))
1820 GOTO 1840
1830 We(I)=Le(I)=0
1840 NEXT I
1850 IF Tem_sol=1 THEN MAT Te=(300) ! INITIAL GUESS FOR TEMP CASE = 27 deg C
1860 IF Tem_sol=0 THEN MAT Pow=(.25) ! INITIAL GUESS FOR POWER = .25 Watts
1870 MAT Le=(.001)*Le
1880 MAT We=(.001)*We
1890 MAT X=(.001)*X
1900 MAT Y=(.001)*Y
1910 MAT Re=Le,We
1920 MAT He=(Hec) ! ASSUME ALL CERAMIC MAKE CORRECTIONS AS NEEDED IN Calc0
1930 Bdl=Bdl+.001
1940 Bdh=Bdh+.001
1950 Areg=Bdl+Bdh/Nreg
1960 Hr=Bqh/Hyr
1970 Lr=Bdl/Nxr
1980 Thick_b=Thick_b+.001
1990 A1=A1+E-6
2000 RETURN ! END OF DATABASE
2010 !
2020 Calc0:GOSUB Error
2030 Calc0: ! ON ERROR GO TO CALC0E
2040 Powtot=Naug=Heaug=Weaug=0

```


THERML .. THERMAL ANALYSIS FOR THERMELEX

```

2050 FOR I=1 TO Nneg
2060 IF Case$(I,I)="#1" THEN He(I)=Hep
2070 IF Itype(I)=0 THEN 2120
2080 Poutot=Poutot+Pow(I)
2090 Weaug=Weaug+(We(I)*.001)/Nneg ! AVG WIDTH INCLUDING PINS
2100 Heaug=Heaug+(He(I)+Lpin)/Nneg ! AVG HEIGHT INCLUDING PINS
2110 Navg=Navg+1/Nyr ! NUMBER OF ELEMENTS IN AN AVG CROSS SECTION
2120 NEXT I
2130 Rair=Bdh*Cb-Navg+Weaug+Heaug
2140 Perim=2*Bdh+2*Navg+Heaug+2*Cb
2150 Fr=1+.5*(Perim-2*Bdh-2*Cb)/Perim ! ROUGHNESS FACTOR
2160 Dh=4*Rair/Perim
2170 Vair=Fair/Rair
2180 Re=Vair*Dh/Gnu
2190 IF Re>1000 THEN Hbf=.023*Kair/Dh*Re^.8 ! TURBULENT AT 1000 DUE
2200 ! ! TO MANY TRIPS OF COMPS
2210 IF Re<1000 THEN Hbf=.540*Kair*Fr/Dh ! LAMINAR FOR 1/Gz>.05
2220 !
2230 Rl_hor=Ln/(Kl+ABS(A1))
2240 Rl_ver=Hr/(Kl+ABS(A1))
2250 Rb_hor=Ln/(Kb+Hr+Thick_b)
2260 Rb_ver=Hr/(Kb+Ln+Thick_b)
2270 RETURN ! END OF CALC0
2280 !
2290 Calc1:GOSUB Error
2300 Calc1: ! THIS SECTION COMPUTES SOME OF THE NON-CHANGING PARAMETERS
2310 ON ERROR GOTO Calc1
2320 FOR I=1 TO Nneg
2330 ! BELOW HERE WE CALCULATE THE CONVECTIVE LOSSES FOR EACH BOARD REGION
2340 IF X(I)/Dh>10 THEN 2390 ! OUTSIDE OF THE DEVELOPMENT REGION
2350 Gz=Re+Pr*Dh/X(I)
2360 Hb=.564*Kair/(1.1+Dh)+.30R/Gz+(1+7.3+.30R(Pr/Gz))/Pr+Fr ! Eq 13.48 KNUTZEN
& KATZ LAMINAR IN DEVELOPMENT REGION
2370 IF 1/Gz>.05 THEN 2390
2380 GOTO 2480
2390 Hb=Hbf
2400 Aregtot=2*Areg-Re(I)
2410 Rb_conu(I)=1/(Hb+Aregtot)
2420 ! NOW WE GET TO THE ELEMENTS ON THE BOARD
2430 IF Itype(I)=0 THEN 2540 ! IF NO ELEMENT THEN SET VERY HIGH RESISTANCE
2440 IF Itype(I)<11 THEN 2480
2450 Dis=.1+Dis
2460 Lpin=.1+Lpin
2470 Aspin=.1+Aspin
2480 Rpins_cond=Lpin/(Kpin+Aspin+Npin(Itype(I)))
2490 Rgap_cond=Dis/(Kair+Re(I))
2500 IF Itype(I)<11 THEN 2540
2510 Dis=10+Dis
2520 Lpin=10+Lpin
2530 Aspin=10+Aspin
2540 Re_cond(I)=Rpins_cond+Rgap_cond/(Rpins_cond+Rgap_cond)
2550 Ab1as=Re(I)+2*Le(I)+He+Aspin+Npin(Itype(I))
2560 Heb1as=Hb
2570 IF I<6 THEN Hb(I)=Hb
2580 Reb1as=1/(Heb1as+Ab1as)
2590 Hestag=.57*Kair*Pr+.4+.30R(Vair/(We(I)*Gnu))
2600 Astag=2*We(I)+He(I)
2610 Restag=1/(Hestag+Astag)

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THERML .. THERMAL ANALYSIS FOR THERMELEN

```

2620 Re_conv(I)=Reblas*Restag/(Pebblas+Restag)
2630 GOTO 2660
2640 Re_conv(I)=1E30
2650 Re_cond(I)=1E30
2660 ! BELOW HERE CALCULATE THE BOARD CONDUCTIVE RESISTANCE
2670 J=1 ! HERE IS BOTTOM OF REGION
2680 IF I=Nxn=Nneg THEN 2720
2690 IF N1(J,I)=0 THEN 2740
2700 R1(J,I)=R1_ver/N1(J,I)+Rb_ver/(R1_ver/N1(J,I)+Rb_ver)
2710 GOTO 2750
2720 R1(J,I)=Rb_ver/2E-40
2730 GOTO 2750
2740 R1(J,I)=Rb_ver
2750 J=2 ! HERE IS RIGHT SIDE OF REGION
2760 IF I MOD Nxn=0 THEN 2800
2770 IF N1(J,I)=0 THEN 2820
2780 R1(J,I)=R1_hon/N1(J,I)+Rb_hon/(R1_hon/N1(J,I)+Rb_hon)
2790 GOTO 2830
2800 R1(J,I)=Rb_hon/2E-40
2810 GOTO 2830
2820 R1(J,I)=Rb_hon
2830 J=3 ! HERE IS THE TOP OF THE REGION
2840 IF I=Nxn THEN 2880
2850 IF N1(J,I)=0 THEN 2900
2860 R1(J,I)=R1_ver/N1(J,I)+Rb_ver/(R1_ver/N1(J,I)+Rb_ver)
2870 GOTO 2910
2880 R1(J,I)=Rb_ver/2E-40
2890 GOTO 2910
2900 R1(J,I)=Rb_ver
2910 J=4 ! HERE IS THE LEFT SIDE OF THE REGION
2920 IF (I-1) MOD Nxn=0 THEN 2960
2930 IF N1(J,I)=0 THEN 2930
2940 R1(J,I)=R1_hon/N1(J,I)+Rb_hon/(R1_hon/N1(J,I)+Rb_hon)
2950 GOTO 3000
2960 R1(J,I)=Rb_hon/2E-40
2970 GOTO 3000
2980 R1(J,I)=Rb_hon
2990 GOTO 3010
3000 Rb_conv(I)=1/(Hb-Anegtot)
3010 NEXT I
3020 !
3030 RETURN ! END OF CALC1
3040 !
3050 Calc_te:GOSUB Error
3060 Calc_t: ! THIS SECTION DETERMINES SURFACE TEMP FROM JUNCTION TEMP AND Rj_c
3070 ON ERROR GOTO Calc_te
3080 IF Tem_sol=1 THEN RETURN
3090 FOR I=1 TO Nneg
3100 Te(I)=Tj(I)-Pow(I)*Rj_c(I)
3110 IF Te(I)<Tair(I)+1.1 THEN Te(I)=Tair(I)+1.1
3120 NEXT I
3130 RETURN !END OF Calc_t
3140 Calc2e:GOSUB Error
3150 Calc2: ! THIS SECTION CONTAINS THOSE PARAMETERS WHICH CHANGE WITH TEMPS
3160 ON ERROR GOTO Calc2e
3170 DISP "WORKING ON CHANGING PARAMETERS"
3180 FOR I=1 TO Nneg
3190 IF Itype(I)<>0 THEN 3230

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THERML ., THERMAL ANALYSIS FOR THERMELEN

```

3200 Rtop_r(I)=1E50
3210 Rgap_rad=1E50
3220 GOTO 3250
3230 Rgap_rad=(Epsr+Epsb-Epsr+Epsb)/(4+Sig+Epsr+Epsb+Re(I)+Te(I)^3)
3240 Rtop_r(I)=((1-Epsb)/(Epsb+Aneg)+10/Aneg+(1-Epsr)/(Re(I)+Epsr))/(4+Sig+Te(I)^3)
3250 Rrote_b(I)=Rgap_rad+Re_cond(I)/(Rgap_rad+Re_cond(I))
3260 Rele(I)=Re_conv(I)+Rrote_b(I)      !!!! MUST BE SUM FOR ALGEBRAIC REASONS
3270 NEXT I
3280 RETURN                                ! END OF CALC2
3290 !
3300 Calc_aire:GOSUB Error
3310 Calc_aire: THIS SECTION FINDS THE AIR TEMPS FOR EACH REGION BASED ON POWER
3320 ON ERROR GOTO Calc_aire
3330 Cfr=Cpa*Fair+Pho
3340 Poutot=0
3350   FOR I=1 TO Nreg
3360     Poutot=Poutot+Pow(I)
3370     Tair(I)=Tair+.5*Pow(I)/Nyr/Cfr
3380     IF (I-1) MOD Nxr=0 THEN 3420
3390     FOR K=I-1 TO I-(I-1) MOD Nxr STEP -1
3400       Tair(I)=Tair(I)+Pow(K)/Nyr/Cfr
3410     NEXT K
3420   NEXT I
3430 Tout=Tair+Poutot/Cfr
3440 RETURN                                ! END OF CALC_AIR
3450 !
3460 Solvee:GOSUB Error
3470 Solvee: THIS SECTION SOLVES THE PROBLEM
3480 ON ERROR GOTO Solvee
3490 DISP "WORKING ON SETTING UP THE MATRIX"
3500 Itt=Itt+1
3510 BEEP
3520 WAIT 300
3530 BEEP
3540 GOSUB Set_up
3550 GOSUB Elu
3560 Err=0
3570 Tmax=0
3580 Pmin=1000
3590 IF Tem_sol=1 THEN 3730
3600   FOR I=1 TO Nreg
3610     Pnew=(Te(I)-B(I))/Rrote_b(I)+(Te(I)-Tair(I))/Re_conv(I)+(Te(I)-B(I))/Rt
op_r(I)
3620     IF Pnew<0 THEN Pnew=Pow(I)/2
3620     IF Pnew<Pmin THEN Pmin=Pnew
3640     IF ABS((Pow(I)-Pnew)/Pow(I))>Err THEN Err=ABS((Pow(I)-Pnew)/Pow(I))
3650     Pow(I)=Pnew
3660   NEXT I
3670   Tmax=500
3680   MAT Tb=B
3690   IF Err<Errmax/100 THEN 3840
3700   GOSUB Calc_t
3710   GOSUB Calc_aire
3720   GOTO 3920
3730   FOR I=1 TO Nreg
3740     Tnew=(Pow(I)+Rrote_b(I)+Re_conv(I)+B(I)+Re_conv(I)+Tair(I)+Rrote_b(I))/
Rele(I)

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THERML .. THERMAL ANALYSIS FOR THERMELEX

```

3750      IF ABS(Te(I)-Tnew)>Err THEN Err=ABS(Te(I)-Tnew)
3760      Te(I)=Tnew
3770      Tj(I)=Te(I)+Pow(I)+Rj_c(I)
3780      IF Tj(I)>Tmax THEN Tmax=Tj(I)
3790      NEXT I
3800      Pmin=0
3810      MAT Tb=B
3820      MAT A=IER
3830      IF Err>Errmax THEN 3920
3840      DISP
3850      FOR C=1 TO 4
3860      BEEP
3870      WAIT 90
3880      BEEP
3890      WAIT 150
3900      NEXT C
3910      RETURN
3920      GOSUB Temp_print
3930      IF (Itt>30) OR (Err>200) OR (Tout>400) THEN GOTO Bomb
3940      GOSUB Calc2
3950      GOTO Solve
3960      !
3970      Set_up: ! THIS SECTION SETS UP THE Nneg SIMUL EQUATIONS IS MATRIX FORM
3980      FOR I=1 TO Nneg
3990      IF Tem_sol=0 THEN B(I)=Te(I)/Rtote_b(I)+Tair(I)/Rb_conv(I)
4000      IF Tem_sol=1 THEN B(I)=(Pow(I)+Re_conv(I)+Tair(I))/Re(I)+Tair(I)/Rb_conv(I)
4010      Ledge=Redge=Tedge=Bedge=1
4020      IF (I-1) MOD Nxr=0 THEN Ledge=2
4030      IF I MOD Nxr=0 THEN Redge=2
4040      IF I<Nxr THEN Tedge=2
4050      IF I+Nxr=Nneg THEN Bedge=2
4060      IF (I-1) MOD Nxr=0 THEN 4080
4070      A(I,I-1)=-1/R(1,I)
4080      IF I MOD Nxr=0 THEN 4100
4090      A(I,I+1)=-1/R(2,I)
4100      IF I<Nxr THEN 4120
4110      A(I,I+Nxr)=-1/R(3,I)
4120      IF I+Nxr=Nneg THEN 4140
4130      A(I,I+Nxr)=-1/R(1,I)
4140      A(I,I)=(Bedge=1)/R(1,I)+(Redge=1)/R(2,I)+(Tedge=1)/R(3,I)+(Ledge=1)/R(4,I)+1/Rtote_b(I)+1/Rb_conv(I)-(Tem_sol=1)+Pe_conv(I)/Re(I)+Rtote_b(I))
4150      NEXT I
4160      RETURN
4170      !
4180      Elu: ! THIS SECTION PERFORMS A LU DECOMPOSITION OF THE A MATRIX
4190      DISP "WORKING ON ITERATION NUMBER ";Itt
4200      Nm1=Nneg-1
4210      FOR K=1 TO Nm1
4220      Kp1=K+1
4230      FOR I=Kp1 TO Nneg
4240      G=-A(I,K)/A(K,K)
4250      A(I,K)=G
4260      FOR J=Kp1 TO Nneg
4270      A(I,J)=A(I,J)+G*A(K,J)
4280      NEXT J
4290      NEXT I
4300      NEXT K

```


THEMNL .. THERMAL ANALYSIS FOR THERMELEN

```

4310 Solver:      ! THIS SECTION SOLVES THE NEW MATRIX AND PLACES THE ANSWERS
4320 Np1=Nneg+1    ! INTO MATRIX B TO BE PASSED BACK TO SOLVE
4330   FOR K=1 TO Nm1
4340     Kp1=K+1
4350     FOR I=Kp1 TO Nneg
4360       B(I)=B(I)+A(I,K)+B(K)
4370     NEXT I
4380   NEXT K
4390 B(Nneg)=B(Nneg)+A(Nneg,Nneg)
4400   FOR K=2 TO Nneg
4410     I=Np1-K
4420     J1=I+1
4430     FOR J=J1 TO Nneg
4440       B(I)=B(I)-A(I,J)+B(J)
4450     NEXT J
4460     B(I)=B(I)/A(I,I)
4470   NEXT K
4480 RETURN                                ! END OF SOLVER
4490 Temp_print:!! THIS SECTION USED FOR INTERMEDIATE OUTPUT
4500 EXIT GRAPHICS
4510 IF (Tempnt=1) AND (Ans=PI) THEN PRINTER IS 0
4520   PRINT SPA(10),"DATA FOR ";Pic(1b1$;"  #";Itt;"ITERATION"
4530   PRINT LIN(2)
4540 FIXED 2
4550   PRINT "PEG #   Tcase (DegC)   Tjunc (DegC)   Treg (DegC)   Pow
(W)   Rj-c(W/C)"
4560   FOR I=1 TO Nneg
4570     PRINT I;TAB(12);Te(I)-273;TAB(26);Tj(I)-273;TAB(41);Tb(I)-273;TAB(52);
Pow(I);TAB(62);Rj_c(I)
4580   NEXT I
4590   PRINT LIN(2)
4600   PRINT "BOARD THICKNESS=";1000+Thick_b;"mm AND CONDUCTIVITY =" ;Kb;"Wat
ts/M-K"
4610   PRINT
4620 GOTO 4690 ! PRINT " I      RB_CONV      RE_CONV      TE      Hb"
4630   FOR I=1 TO 5
4640     PRINT USING 4660;I,Fb_conv(I),Re_conv(I),Te(I)-273,Hb(I)
4650   NEXT I
4660   IMAGE DD,4X,4(4D.4D,4X)
4670   PRINT
4680   FIXED 4
4690   PRINT "COOLING AIR FLOW OF ":Fair;"M^3 per SEC   VEL=";Vair;"M/Sec","(
;Vair*39/3;"FT/3)",LIN(1)
4700   PRINT "INLET AIR TEMP=";Tair-273;" deg C   OUTLET AIR TEMP=";Tout-273;"de
g C"
4710 PRINT LIN(2),"LARGEST DIFFERENCE BETWEEN ITERATIONS =" ;Err;"*****"
4720 PRINT "
",LIN(2)
-----
4730   PRINTER IS 16
4740   STANDARD
4750   RETURN
4760 Debug: Ans$="N"! TEMP DEBUG FOR RESISTANCES
4770 RETURN !
4780 INPUT "DO YOU WISH TO HAVE A LIST OF ALL THE RESISTANCES PRINTED (NO or YES
)?",Ans$
4790 IF UPC(Ans$(1,1))="N" THEN RETURN
4800 PRINTER IS 0
4810 FIXED 5

```


THERML .. THERMAL ANALYSIS FOR THEPMELEM

```

4820 PRINT "   REG#   RE COND   RE CONV   PTOTE B   RTOP R   RB
CONV"
4830 FOR I=1 TO Nreg
4840 ! PRINT TAB(2),I,TAB(4),Re_cond(I),TAB(4),Re_conv(I),TAB(4),Rtote_b(I),TAB(
5);Rtop_r(I),TAB(4),Rle(I)
4850 PRINT TAB(2),I;Re_cond(I);Re_conv(I);Rtote_b(I);Rtop_r(I);Rb_conv(I)
4860 NEXT I
4870 PRINTER IS 16
4880 STANDARD
4890 RETURN
4900 Units:!! THIS SECTION CONVERTS FROM METER TO mm
4910 Bdl=1000*Bdl! HERE CORRECT UNITS FOR USE IN GRAPHICS AND TO REWORK ANALYSIS
4920 Bdh=1000*Bdh
4930 MAT X=(1000)*X
4940 MAT Y=(1000)*Y
4950 MAT Le=(1000)*Le
4960 MAT We=(1000)*We
4970 Thick_b=1000*Thick_b
4980 A1=A1*1E5
4990 RETURN
5000 ! END OF Units
5010 Outputs: GOSUB Error
5020 Output:!! THIS SECTION OUTPUTS TO GRAPHICS ON A BLANK BOARD
5030 ON ERROR GOTO Output
5040 PLOTTER IS "GRAPHICS"
5050 GRAPHICS
5060 MSCALE 0,10
5070 CSIZE 2
5080 LOG 5
5090 MOVE 10,130
5100 LABEL "---air flow----> "
5110 CSIZE 3
5120 Bdh=Bdh/Sca
5130 Bdl=Bdl/Sca
5140 IF Sca=1 THEN 5220
5150 LOG 6
5160 LDIR PI/2
5170 MOVE 175,70
5180 IF Sca>1 THEN LABEL "THIS PICTURE IS 1/XVAL#(Sca)& " SIZE"
5190 IF Sca<1 THEN LABEL "THIS PICTURE IS 2X SIZE"
5200 LOG 5
5210 LDIR 0
5220 MOVE 100-LEN("OUTPUT DATA FOR "&Pict1b1$)/2,135
5230 LABEL USING "K": "OUTPUT DATA FOR "&Pict1b1$
5240 MOVE 0,0
5250 DRAW 0,Bdh
5260 DRAW Bdl,Bdh
5270 DRAW Bdl,0
5280 DRAW 0,0
5290 LINE TYPE 3
5300 Lr=Bdl/Nxr
5310 Hr=Bdh/Hyr
5320 FOR I=1 TO Nxr-1
5330 MOVE I*Lr,0
5340 DRAW I*Lr,Bdh
5350 NEXT I
5360 FOR I=1 TO Hyr-1
5370 MOVE 0,I*Hr

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THERML .. THERMAL ANALYSIS FOR THERMELEX

```

5380   DRAW Bdl,I*Hr
5390   NEXT I
5400   LINE TYPE 1
5410   LONG 8
5420   Nr=0
5430   CSIZE 2.4
5440   FOR I=1 TO Nneg
5450     MOVE X(I)-.35*Ln,Y(I)+.35*Hr
5460     LABEL USING "K";VAL(I)
5470     MOVE X(I)+.3*Ln,Y(I)+.25*Hr
5480     LABEL USING "K";Type(I)
5490     IF Itype(I)=0 THEN 5570
5500     IF Tj(I)-273<.95*(Tmax-273) THEN LABEL USING 5610:Tj(I)-273
5510     IF Tj(I)-273>=.95*(Tmax-273) THEN LABEL USING 5600:Tj(I)-273
5520     IF Pow(I)<=1.05*Pmin THEN LABEL USING 5630:Pow(I)
5530     IF Pow(I)>1.05*Pmin THEN LABEL USING 5620:Pow(I)
5540     LABEL USING 5610:Te(I)-273
5550     GOTO 5590
5560     !
5570     LABEL USING "K";""
5580     LABEL USING 5610:Tb(I)-273
5590   NEXT I
5600   IMAGE "++",DDD,D," C"
5610   IMAGE DDD,D," C"
5620   IMAGE D,DDD," W"
5630   IMAGE "++",D,DDD," W"
5640   FIXED 4
5650   DUMP GRAPHICS
5660   PRINTER IS 0
5670   PRINT SPA(20),"
5680   PRINT SPA(20),"
5690   PRINT SPA(20),"
5700   PRINT SPA(20),"
5710   PRINT SPA(20),"
5720   PRINT SPA(20),"
5730   PRINT SPA(20),"
5740   PRINT LIN(2)
5750   PRINT SPA(14);" FLOW RATE"
5760   PRINT USING 5800;"COOLING AIR ":Fain;"M-3/Sec";Vain;"M/Sec";Tain-273;"
deg C";Tout-273;"deg C"
5770   STANDAPD
5780   IF Tem_sol=0 THEN PRINT USING 5810;"LARGEST CHANGE IN POWER BETWEEN ITERAT
IONS #";Itt-1;" AND #";Itt;" = ";Err
5790   IF Tem_sol=1 THEN PRINT USING 5810;"LARGEST CHANGE IN TEMP BETWEEN ITERATI
ONS #";Itt-1;" AND #";Itt;" = ";Err
5800   IMAGE 11A,2X,.4D,7A,2X,DD,4D,5A,2X,3D,D,5A,2X,3D,D,5A
5810   IMAGE //45A,DD,6A,DD,A,DD,4D
5820   ! MORE OF THE CIRCUIT DESCRIPTION CAN BE PRESENTED HERE
5830   PRINT LIN(1),"CIRCUIT BOARD DESCRIPTION IS STORED UNDER ";CHR$(132);Name#;
CHR$(128)
5840   PRINT "
"
5850   PRINTER IS 16
5860   EXIT GRAPHICS
5870   RETURN
5880   !
5890   What_now:GOSUB Error
5900   What_now: THIS SECTION PRESENTS THE VARIOUS OPTIONS AVAILABLE AND DIRECTS

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THERM .. THERMAL ANALYSIS FOR THERMELEN

```

5910          I PROGRAM CONTROL AS NEEDED
5920 ON ERROR GOTO What_nowe
5930 S$="WHAT NOW ?"
5940 GOSUB Pagehead
5950 PRINT TAB(15),"You have completed the thermal analysis of : "
5960 PRINT TAB(37-LEN(Pict1b1$)/2);CHR$(129);Pict1b1$;CHR$(129)
5970 PRINT TAB(17),"the options available are listed below:"
5980 PRINT LIN(1),TAB(5),"1. CHANGE COOLING AIR PARAMETERS AND RE-ANALYZE ";CHR
$(132);Name$;CHR$(128);"."
5990 PRINT LIN(1),TAB(5),"2. SENSITIVITY ANALYSIS FOR CHANGES IN COOLING AIR PA
RAMETERS OF ";CHR$(132);Name$;CHR$(128);"."
6000 PRINT LIN(1),TAB(5),"3. MAKE CHANGES TO BOARD DESCRIPTION IN FILE NAME ";C
HR$(132);Name$;CHR$(128);"."
6010 PRINT LIN(1),TAB(5),"4. RETRIEVE A NEW BOARD DESCRIPTION FROM MASS STORAGE
."
6020 PRINT LIN(1),TAB(5),"5. INPUT A NEW BOARD DESCRIPTION FROM THE KEYBOARD."
6030 PRINT LIN(1),TAB(5),"6. TERMINATE SESSION"
6040 Map=Board=0
6050 Ans$="1"
6060 INPUT "YOUR CHOICE FROM ABOVE (1,2,3,4,5,6)?",Ans$
6070 IF Ans$="BACK_UP" THEN RETURN
6080 Ans=INT(VAL(Ans$))
6090 IF (Ans>0) AND (Ans<=6) THEN 6120
6100 GOSUB Errin
6110 GOTO What_now
6120 ON Ans GOSUB Pedit,Sensi,Change,Get_new,Key_new,Terminate
6130 IF Ans=1 THEN RETURN
6140 GOTO What_now
6150 Redo: RETURN ! THIS WILL ALLOW RESTART OF THIS PROGRAM WITH SAME BOARD
6160 !
6170 Sensie:GOSUB Error
6180 Sensi: ! THIS SECTION PRODUCES PLOTS OF OUTPUT VS COOLING AIR PARAMETERS
6190 ON ERROR GOTO Sensie
6200 S$="SENSITIVITY ANALYSIS"
6210 GOSUB Pagehead
6220 PRINT " This section allows you to investigate the effects of variations
in the air flow rate. "
6230 IF Tem_sol=1 THEN PRINT "Plots of Maximum Junction Temperature vs Flow Rate
of the air are produced"
6240 IF Tem_sol=0 THEN PRINT "Plots of Minimum Power vs Flow rate of the air are
produced."
6250 PRINT " You specify the maximum flow rate per board (M^3/sec) and five s
eparate "
6260 PRINT "analyses are performed and the results plotted. NOTE: selecting a m
aximum flow"
6270 PRINT "that is evenly divisible by five (5,10,30) will result in better loo
king axes.",LIN(1)
6280 PRINT "These plots may be produced on either the screen (with hard copy via
Key3) or "
6290 PRINT "on a peripheral plotter such as the Hp 9872A. In addition a printed
tabular"
6300 PRINT "output of the results at each of the airflow rates may be produced."
6310 PRINT
6320 Ans$="NULL"
6330 INPUT "WHAT IS THE UPPER LIMIT ON THE AIR FLOW RATE FOR THE SENSITIVITY ANA
LYSIS?",Ans$
6340 IF Ans$="BACK_UP" THEN What_now
6350 IF Ans$="NULL" THEN 6320

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THERML .. THERMAL ANALYSIS FOR THERMELEM

```

6360 Ans=ABS(VAL(Ans$))
6370 Xmax=Ans
6380 Xmin=0
6390 Xstep=(Xmax-Xmin)/5
6400 Ymin=0
6410 Mult=100000
6420 IF Xmax>=.001 THEN Mult=10000
6430 IF Xmax>=.01 THEN Mult=1000
6440 IF Xmax>=.1 THEN Mult=100
6450 Ans$="N"
6460 INPUT "DO YOU WISH TO HAVE TABULAR RESULTS FOR EACH OF THE AIR FLOWS?(N or
Y)",Ans$
6470 IF Ans$="BACK_UP" THEN Sensi
6480 Tempnt=0
6490 IF UPC$(Ans$)="Y" THEN Tempnt=1
6500 GOSUB Database
6510 Map=1
6520 IF Tem_sol=1 THEN 6550
6530 FOR Fair=Xmax TO Xstep STEP -Xstep
6540 GOTO 6560
6550 FOR Fair=Xstep TO Xmax STEP Xstep
6560 GOSUB Calc0
6570 GOSUB Calc1
6580 GOSUB Calc_t
6590 GOSUB Calc2
6600 GOSUB Calc_ain
6610 GOSUB Solve
6620 IF Tem_sol=1 THEN Y=Tmax-273
6630 IF Tem_sol=0 THEN Y=Pmin
6640 IF Tempnt=1 THEN PRINTER IS 0
6650 IF Tempnt=1 THEN GOSUB Temp_print
6660 IF Map=1 THEN GOSUB Plot
6670 IF Ans$="BACK_UP" THEN 6450
6680 Ans=Itt=Map=0
6690 GRAPHICS
6700 PEN 1
6710 MOVE Fair,Y
6720 LOGO 5
6730 LABEL USING "K";"*"
6740 PEN 0
6750 NEXT Fair
6760 EXIT GRAPHICS
6770 DUMP GRAPHICS
6780 PRINTER IS 0
6790 PRINT LINK(2)
6800 PRINTER IS 16
6810 GOSUB Units
6820 GOTO What_now
6830 !
6840 Change: ! THIS SECTION LOADS BOARDS TO ALLOW CHANGES TO THE CIRCUIT DESCRIPT
6850 Map=1
6860 PRINT PAGE
6870 DISP "WORKING LOADING BOARDS"
6880 LOAD "BOARDS",1
6890 Get_new: ! THIS SECTION EXPLAINS THE TWO WAYS TO GET A NEW BOARD DESCRIPTION
6900 S$="INPUT OF NEW BOARD DESCRIPTION"
6910 GOSUB Pagehead
6920 PRINT "      The new board description may be read in from mass storage in tw
o different"

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! END OF SENSI

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6930 PRINT "programs. THERML (the program in core now) will not allow visual
checking on"
6940 PRINT "modification of descriptive data for the circuit board. The data is
read in"
6950 PRINT "at your direction but only questions concerning the environment exte
rior to the"
6960 PRINT "circuit board are asked. The second method of input from mass stora
ge involves"
6970 PRINT "the program BOARDS which allows both data checking through graphic
s and "
6980 PRINT "opportunities to modify the descriptive data."
6990 PRINT
7000 PRINT LIN(1),TAB(5),"1. READ A NEW BOARD DESCRIPTION USING THERML. (no c
orrections)"
7010 PRINT LIN(1),TAB(5),"2. READ A NEW BOARD DESCRIPTION USING BOARDS. (allo
ws corrections)"
7020 PRINT LIN(2)," REMEMBER THE THERMELEX SYSTEM MUST BE IN THE DEFAULT MASS ST
ORAGE DEVICE"
7030 Ans$="1"
7040 INPUT "YOUR CHOICE FROM ABOVE (1,2)?",Ans$
7050 IF Ans$="BACK_UP" THEN What_now
7060 Ans=VAL(Ans$)
7070 IF (Ans>0) AND (Ans<3) THEN 7100
7080 GOSUB Errin
7090 GOTO Get_new
7100 IF Ans=2 THEN 7130
7110 Map=1
7120 RETURN
7130 !
7140 Map=2
7150 DISP "WORKING LOADING BOARDS"
7160 LOAD "BOARDS",1
7170 !
7180 Key_new: ! THIS SECTION LOADS BOARDS WITH THE INTENT TO INPUT NEW BOARD DESC
7190 Map=3
7200 DISP "WORKING LOADING BOARDS"
7210 LOAD "BOARDS",1
7220 !
7230 Terminate: ! THIS SECTION TERMINATES THE SESSION
7240 GCLEAR
7250 DISP "WORKING LOADING STANDARD KEY DEFFINITIONS"
7260 LOAD KEY "STDKEY"
7270 PRINT LIN(20),SPA(15),"NORMAL TERMINATION"
7280 PRINT LIN(2),SPA(15)," THANK YOU "
7290 DISP
7300 END
!END OF TERMINATE
7310 !
7320 Pagehead: ! THIS ROUTINE PLACES THE PAGE HEADINGS FOR THE INSTRUCTIONS
7330 PRINT PAGE,TAB(34-LEN(S$)*2),"** ";CHR$(132);S$;CHR$(133);" **",LIN(2)
7340 RETURN
7350 !
7360 Errin: ! THIS SECTION ALERTS THE USER TO AN ATTEMPT TO INPUT BAD DATA
7370 BEEP
7380 DISP "***** INPUT OUT OF RANGE.....TRY AGAIN"
7390 WAIT 1500
7400 BEEP
7410 RETURN
! END OF ERRIN
7420 !

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7430 Error:!! THIS SECTION IS THE ERROR TRAPPING ROUTINE FOR THE ENTIRE PROGRAM
7440      ! PROGRAM FLOW RESUMES AT THE TOP OF THE SECTION IN WHICH THE ERROR
7450      ! OCCURED AFTER THE USER PASSES CONT
7460 EXIT GRAPHICS
7470 PRINTER IS 16
7480 PRINT PAGE
7490 BEEP
7500 WAIT 300
7510 BEEP
7520 IF ERRN=56 THEN Err_name
7530 PRINT LIN(20),SPAC(10),"ERROR NUMBER";ERRN;"HAS OCCURED IN LINE";ERRL;".  PR
ESS CONT WHEN READY"
7540 DISP
7550 BEEP
7560 PAUSE
7570 RETURN
7580 !
7590 Err_name:!! THIS SECTION FOR IMPROPER FILE NAME
7600 PRINTER IS 16
7610 PRINT PAGE
7620 Msus$="DEFAULT MASS STORAGE"
7630 FOR I=2 TO LEN(Name$)
7640 IF Name$(I,I)="/" THEN 7670
7650 NEXT I
7660 GOTO 7700
7670 Msus$=Name$(I)
7680 CAT Msus$
7690 GOTO 7710
7700 CAT
7710 PRINT LIN(2),"File Name ";CHR$(132);Name$(I,I-1);CHR$(128);" is NOT on ";CH
R$(132);Msus$;CHR$(128);" with that spelling....."
7720 PRINT LIN(1),"CHECK OVER THE DIPECTORY ABOVE FOR CORRECT NAME OR SPELLING..
."
7730 DISP "PRESS CONT WHEN READY"
7740 PAUSE
7750 RETURN      ! END OF ERROR
7760 Plote:GOSUB Error
7770 Plot: ! PLOTTING ROUTINE FOR THE AXES
7780 ON ERROR GOTO Plote
7790 PLOTTER IS "GRAPHICS"
7800 IF Tem_sol=0 THEN 7880
7810 Ystep=10
7820 FOR I=0 TO 7
7830 IF Tmax-273>50+I*25 THEN Ystep=15+I*5
7840 NEXT I
7850 Plt1bl$="Tjunc vs Air Flow"
7860 Y1bl$="Junc Temp (deg C)"
7870 GOTO 7940
7880 Ystep=.1
7890 FOR I=1 TO 10
7900 IF Pmin>.5+I THEN Ystep=.1+(I+1)
7910 NEXT I
7920 Plt1bl$="Pmin vs Air Flow"
7930 Y1bl$="Min Power/Comp (Watts)"
7940 Ymax=5+Ystep
7950 GRAPHICS
7960 LOCATE 15,120,10,95
7970 SCALE Xmin,Ymax,Ymin,Ymax

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7980 AXES Xstep,Ystep,Xmin,Ymin
7990 CSIZE 3
8000 LDIR 0
8010 LOG 5
8020 FOR Xpos=Xmin TO Xmax STEP Xstep
8030 MOVE Xpos,Ymin-.1*Ystep
8040 LABEL USING "k";Xpos*Mult
8050 NEXT Xpos
8060 MOVE 2.5*Xstep,-.4*Ystep
8070 LABEL USING "k";"Air-Flow/Board (<%VAL$(1/Mult)&" M^3/Sec)"
8080 LOG 9
8090 FOR Ypos=Ymin TO Ymax STEP Ystep
8100 MOVE Xmin-.1*Xstep,Ypos
8110 LABEL USING "k";Ypos
8120 NEXT Ypos
8130 LINE TYPE 1
8140 LOG 4
8150 LDIR PI/2
8160 MOVE -.4*Xstep,2.5*Ystep
8170 LABEL USING "k";Yib1$
8180 MOVE Xmin+2.5*Xstep,5.1*Ystep
8190 CSIZE 4
8200 LDIR 0
8210 LABEL USING "k";Pict1b1$
8220 LABEL USING "k";Pit1b1$
8230 RETURN
8240 !
8250 Bomb: ! THIS SECTION DELIVERS MESSAGE TO THE USER OF FAILURE TO CONVERGE
8260 WAIT 2000
8270 BEEP
8280 PRINT PAGE,LINK(10),"UNABLE TO ACHIEVE CONVERGENCE DUE TO NUMERICAL INSTABILITIES"
8290 PRINT LINK(3),"I SUGGEST A CHANGE IN EITHER THE INSTALLATION PARAMETERS OR"
8300 PRINT LINK(1),"THE CIRCUIT BOARD PARAMETERS ...."
8310 PRINT LINK(2),"THERMELEX PREDICTS TEMPERATURES MUCH MUCH BETTER THAN POWER LEVELS"
8320 PRINT LINK(1),"TRY SPECIFYING THE COMPONENT POWER LEVELS.",LINK(3)
8330 DISP "Press CONT when ready to return to option list"
8340 BEEP
8350 PAUSE
8360 DISP
8370 Bomb=1
8380 RETURN

```

! END OF PLOT

! END OF BOMB

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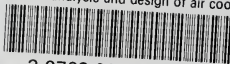
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